

PIMAL: Phantom with Moving Arms and Legs

Version 4.1.0

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PIMAL: Phantom with Moving Arms and Legs

Version 4.1.0

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ABSTRACT

Computational phantoms with articulated arms and legs have been developed to enable radiation dose estimation for male and female receptors in different postures. Using a user-friendly graphical user interface (GUI), the PIMAL (**P**hantom **w**ith **M**oving **A**rms and **L**egs) software can be employed to adjust the posture of a phantom, generate a corresponding input file for the Monte Carlo N-Particle (MCNP®) radiation transport code, and perform the radiation transport simulations for the dose calculations in MCNP®. The MCNP® code can be run natively from the PIMAL interface or externally in the MCNP® command prompt via the generated MCNP® PIMAL input file.

Before PIMAL 4.0, previous versions consisted of a single (hermaphrodite) phantom model. PIMAL 4.1.0 now includes a separate male and female stylized phantom with articulated limbs, in addition to housing the most recent International Commission on Radiological Protection (ICRP) Publication 110 reference adult male and female voxel phantoms (no articulation). Both internal and external radionuclide sources can be simulated in PIMAL via a dropdown menu in the GUI. For external sources, the user can select the ICRP's standard external exposure geometries (AP, PA, LLAT, RLAT, or ISO), in addition to a point source, from the menu options.

PIMAL 4.1.0 contains an improved user interface. The design of the sliders to control the articulation of the limbs is connected with the textbox input, with the bounding conditions of limb articulation included. Source modes (i.e., photon, neutron) for Monte Carlo simulation have been pre-programmed with the source input (photon, neutron, x-ray, radionuclide) to simplify the definition of the radiation source.

This user manual describes the updates to PIMAL 4.1.0, in addition to aiding the user in installing PIMAL, exploring the geometry articulation and visualization capabilities, and radiation source definitions, in addition to providing sample tutorials for the PIMAL user for estimating organ doses.

TABLE OF CONTENTS

ABSTRACT.....	iii
LIST OF FIGURES.....	vii
ACKNOWLEDGMENTS.....	ix
ABBREVIATION AND ACRONYMS.....	xi
1 INTRODUCTION	1-1
1.1 Manual Outline.....	1-2
1.2 User Requirements.....	1-2
2 PIMAL VERSION 4.0 AND 4.1.0 FEATURES	2-1
3 INSTALLATION	3-1
3.1 The PIMAL Installer	3-1
3.2 Configuration of PIMAL	3-11
3.2.1 Setting the Working Directory	3-11
3.2.2 Setting the Path for MCNP® Executable.....	3-12
4 WORKSPACE	4-1
4.1 GUI Overview	4-1
4.2 Camera Controls.....	4-2
4.3 Using the Sliders window	4-2
4.4 Using the Text window	4-4
4.5 Setting Phantom Transparencies	4-5
4.6 Resetting the Phantom	4-5
4.7 Two-Dimensional View	4-6
4.8 Saving Current Configuration	4-6
4.9 Recalling Past Configurations	4-7
4.10 Exiting PIMAL	4-7
5 GENERATING MCNP® INPUTS	5-1
5.1 PIMAL Built-in Source Settings	5-1
5.2 Generating MCNP® Input	5-2
5.3 Displaying Source Points.....	5-3
5.4 Saving Input.....	5-4
5.5 Entering Custom Source Configurations.....	5-5
6 RUNNING MCNP®	6-1
6.1 Running MCNP® through PIMAL	6-1
6.2 Running MCNP® through the Command Prompt	6-3
6.3 Viewing Organ Dose.....	6-5
7 TUTORIALS	7-1
7.1 Female Extension Pose (AP Source) - Beginner User.....	7-1
7.2 Male Voxel Phantom (AmBe Point Source) - Intermediate User.....	7-8
7.3 Water Submersion - Advanced User	7-12
8 REFERENCES	8-1
APPENDIX A DETAILED DESCRIPTION OF PHANTOM INPUT FILES.....	A-1

LIST OF FIGURES

Figure 1	PIMAL Installer	3-1
Figure 2	PIMAL Setup Wizard	3-1
Figure 3	Choose Install Location	3-2
Figure 4	Choose Start Menu Folder	3-2
Figure 5	PIMAL Installation Process	3-3
Figure 6	Start JDK Installation	3-4
Figure 7	JDK Custom Installation Setup	3-5
Figure 8	JDK Installer Extraction	3-5
Figure 9	Select Destination Folder for JDK	3-6
Figure 10	JDK Installation	3-6
Figure 11	JDK Installation Complete	3-7
Figure 12	Start Java 3D™ Installation	3-8
Figure 13	Java 3D™ Installation Confirmation	3-8
Figure 14	Java 3D™ Installation Complete	3-9
Figure 15	PIMAL Installation Complete	3-10
Figure 16	Close PIMAL Setup Wizard	3-10
Figure 17	PIMAL After Installation	3-11
Figure 18	Working Directory Window	3-11
Figure 19	Second Working Directory Window	3-12
Figure 20	MCNP® Executable Window	3-12
Figure 21	MCNP® Executable Path Selection	3-13
Figure 22	Location of MCNP6® Executable	3-13
Figure 23	PIMAL Graphical User Interface	4-1
Figure 24	Default PIMAL Stance - Sliders	4-2
Figure 25	PIMAL with Left Shoulder Rotated 90 Degrees - Sliders	4-3
Figure 26	Default PIMAL Stance - Text	4-4
Figure 27	PIMAL with Left Shoulder Rotated 90 Degrees - Text	4-4
Figure 28	Checking the Bones, Lungs, and Heart Transparency Boxes	4-5
Figure 29	Phantom and Reset Button	4-5
Figure 30	2D View Workspace	4-6
Figure 31	Opening PIMAL Input	4-7
Figure 32	Exiting PIMAL through Toolbar	4-7
Figure 33	Depiction of Simulation Tab on Sidebar	5-1
Figure 34	Generate MCNP® Input Window	5-3
Figure 35	Source Point Display of LLAT Geometry	5-4
Figure 36	Setting Transparent Organs and Save Input Location	5-5
Figure 37	Save Input Window	5-5
Figure 38	MCNP® Screen Output	6-1
Figure 39	Tabulated Organ Doses	6-2
Figure 40	Fatal Error Warning	6-2
Figure 41	Command Prompt on Windows®	6-3
Figure 42	Changing Working Directory	6-3
Figure 43	Running the Input File	6-4
Figure 44	Pausing the Run	6-4
Figure 45	Organ Dose Chart	6-5
Figure 46	Output Selection Window	6-5
Figure 47	Female Phantom in Extension Pose	7-1
Figure 48	Open Mathematical Female Phantom	7-2
Figure 49	Phantom Parameters Window - Female Extension	7-2
Figure 50	Phantom Sliders Tab - Female Extension	7-2

Figure 51	Phantom Simulation Tab - Female Extension	7-3
Figure 52	Set Source Display Number - Female Extension	7-3
Figure 53	MCNP® Input - Female Extension	7-4
Figure 54	Female Extension Phantom with Source Point Display (<i>Posterior View</i>)	7-5
Figure 55	Female Extension MCNP® Run.....	7-6
Figure 56	Female Extension Phantom Computed Organ Dose Values	7-7
Figure 57	Male Voxel Phantom	7-8
Figure 58	Open ICRP's MALE Voxel Phantom Model	7-9
Figure 59	Phantom Simulation Tab - Male Voxel	7-9
Figure 60	MCNP® Input - Male Voxel	7-10
Figure 61	Save MCNP® Input File - Male Voxel	7-10
Figure 62	MCNP® Command Prompt - Male Voxel	7-11
Figure 63	PIMAL View Organ Dose - Male Voxel.....	7-11
Figure 64	Male Voxel Phantom MCNP® Output.....	7-12
Figure 65	Water Submersion with Male Mathematical Phantom.....	7-13
Figure 66	Open Mathematical Male Phantom	7-13
Figure 67	Phantom Simulation Tab - Water Submersion	7-14
Figure 68	MCNP® Input 1 - Water Submersion	7-14
Figure 69	MCNP® Input 2 - Water Submersion	7-15
Figure 70	MCNP® Input 3 - Water Submersion	7-15
Figure 71	MCNP® Input 4 - Water Submersion	7-16
Figure 72	MCNP® Input 5 - Water Submersion	7-17
Figure 73	MCNP® Command Prompt - Water Submersion	7-18
Figure 74	PIMAL View Organ Dose - Water Submersion.....	7-18
Figure 75	Water Submersion MCNP® Output	7-19

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ABBREVIATIONS AND ACRONYMS

AP	antero-posterior
GUI	graphical user interface
ICRP	International Commission on Radiological Protection
JDK	Java Development Kit
LLAT	left lateral
MCNP®	Monte Carlo N-Particle
NPS	Number of Particles
NRC	[United States] Nuclear Regulatory Commission
PA	postero-anterior
PIMAL	Phantom w/ltH Moving Arms and Legs
RLAT	right lateral
SDEF	source definition

1 INTRODUCTION

Computational models of the human anthropomorphic phantom have undergone progressive evolution since their initial development in the 1970s [1]. Computational phantoms employed by the Nuclear Regulatory Commission (NRC) were largely based on a model published in 1974, which did not account for select organs (e.g., neck, esophagus) and tissues. These deficiencies were compounded by inaccurate organ placement within the body (e.g., thyroid). Most notably, all the computational phantoms were assumed to be in the vertical-upright position, which continues to be a trend in the development of current computational phantoms. To assess the radiation dose in non-standard positions (e.g., occupational exposure or public exposure in a radiologically significant event), the mathematical phantom has been revised to enable articulation of arms and legs. The revised phantom is called PIMAL: Phantom with Moving Arms and Legs [2], [3].

In the initial phase of development in 2007, the objectives for developing PIMAL were three-fold: (1) update the MIRD-5 mathematical phantom model that was being used by the NRC staff to improve the assessment of dose for realistic exposure configurations; (2) perform benchmark computations against International Commission on Radiation Protection (ICRP) Publication 74 values [4] and investigate the reasons behind any identified discrepancies; and (3) develop an interface to assist the user (or analyst) in using the updated phantom model in dose assessment activities.

The organs and compositions of anthropomorphic phantom models were updated, and the revised computational phantom model was adopted for radiation transport codes, notably the Monte Carlo N-Particle (MCNP®) code [5]. Computationally generated results were compared against values reported by the ICRP in Publication 74 [4], with identified discrepancies being resolved. Although the original PIMAL phantom was developed as an adult hermaphrodite model, with both male and female gender-specific organs, the latest revision of PIMAL separates the male and female option for calculating doses. Furthermore, extensive benchmarking, in addition to sensitivity computations, was performed to determine the sensitivity of the organ doses for certain parameters, including composition and cross sections used in the simulations [2]. Finally, a graphical user interface (GUI) has been developed to assist the analyst with input preparation and output manipulation [6]. The GUI can be used to visualize the positioning of the arms and legs as the desired posture is achieved to generate the input file, conduct radiation transport simulations, and extract the organ dose values from the MCNP® output file. A phantom model was included in the GUI, thus enabling visualization of the arms and legs as they are positioned using slider bars. Once the user decides on the posture, an MCNP® input file can be generated and the radiation transport simulations using MCNP® can be performed through the GUI. Furthermore, the computed organ dose values can be extracted (from the MCNP® output file), displayed, and exported as an ASCII file.

1.1 Manual Outline

This user manual describes the updates to PIMAL 4.1.0, in addition to aiding the user in installing PIMAL, exploring the geometry articulation and visualization capabilities, and radiation source definitions, in addition to providing sample tutorials for the PIMAL user for estimating organ doses.

The organization of this manual is as follows:

- Section 2 outlines the updates made to PIMAL version 4.0 and version 4.1.0
- Section 3 details the installation and setup procedures for PIMAL
- Section 4 walks through PIMAL functionality
- Section 5 details the generation of MCNP® input
- Section 6 demonstrates how to run MCNP® with PIMAL
- Section 7 outlines a few examples and tutorials:
 - Female Extension Pose (AP Source) - Beginner User
 - Male Voxel Phantom (AmBe Point Source) - Intermediate User
 - Water Submersion - Advanced User
- Appendix A provides a detailed explanation of the PIMAL-generated MCNP® input decks
- Appendix B lists the range of motion limitations with the PIMAL appendages
- Appendix C provides references for locating the PIMAL benchmark work

1.2 User Requirements

PIMAL 4.1.0 employs Java-3D™ and currently only compatible with Microsoft Windows® (7, 8, 10) operating systems at this time.

Note that PIMAL 4.1.0 has been successfully installed and executed on Parallels Desktop® for Mac®. The developers do not endorse any single software product, but only provide feedback based on successful test cases.

2 PIMAL VERSION 4.0 AND 4.1.0 FEATURES

PIMAL permits custom articulation of limbs. With both male and female phantom models included, PIMAL supports the ability to manipulate the phantom's position using a simple GUI and generate files supporting execution using MCNP® transport code.

A variety of updates have been implemented in PIMAL Version 4.0. The practical features of the software include:

- Java 3-dimensional (3D)[™] interface for PIMAL display;
- Sliders and text options to move appendages;
- ICRP's reference voxel phantoms;
- 2D cross sectional view;
- Organ dose tabulation;
- Source point display; and,
- Saving/loading PIMAL configuration.

In PIMAL Version 4.1.0, the following changes were made:

- Updated the underlying JAVA 3D[™] interface for an optimized user experience;
- Updated the voxel phantoms to the latest ICRP Publication 110 models [7] (male/female adult, not articulated);
- Updated the Help page to access the PDF Manual;
- Updated the Simulation tab:
 - Removed the MODE button; MODE is now automatically selected based on the emission criteria of the selected nuclide; and,
 - Set point source to be 1 m above ground in front of the phantom.
- Made Help file and output windows full screen by default; and,
- Facilitated the link of PIMAL to MCNP®, negating the set DATAPATH step.

3 INSTALLATION

Instructions for installing PIMAL on a Microsoft Windows® system are provided below.

3.1 The PIMAL Installer

The installation process for PIMAL is similar to that for installing other Windows® programs.

Step 1. Locate the PIMAL installer file and double click the icon.

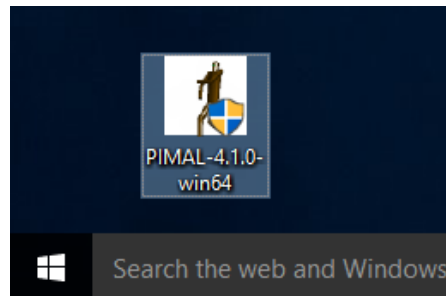


Figure 1 PIMAL Installer

Step 2. The *PIMAL Setup Wizard* welcome screen appears. Select *Next* to continue.



Figure 2 PIMAL Setup Wizard

Step 3. Choose a specific destination folder by selecting *Browse* or keep the default location. Select *Next* to continue.

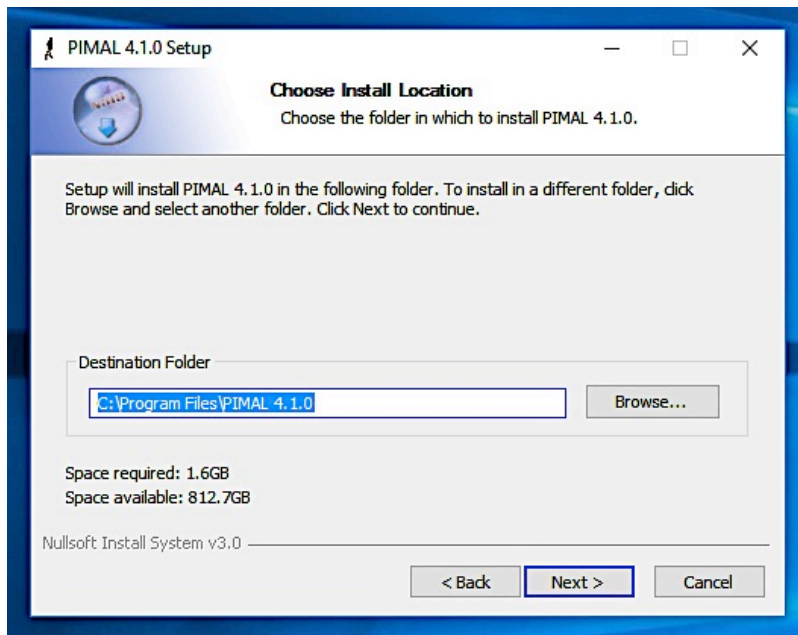


Figure 3 Choose Install Location

Step 4. Choose a specific Start Menu Folder or keep the default entry and select *Install* to begin the installation.

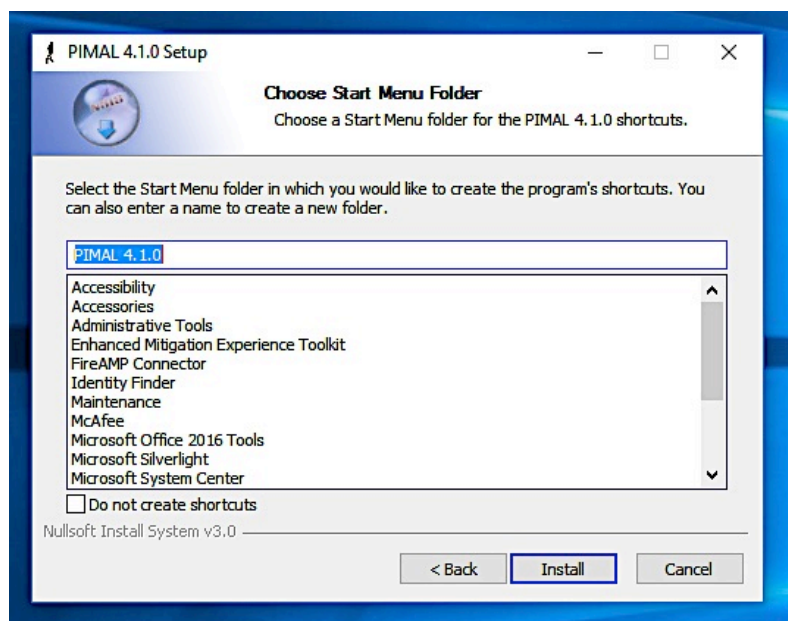


Figure 4 Choose Start Menu Folder

The PIMAL installer begins setting up the PIMAL application on the machine.

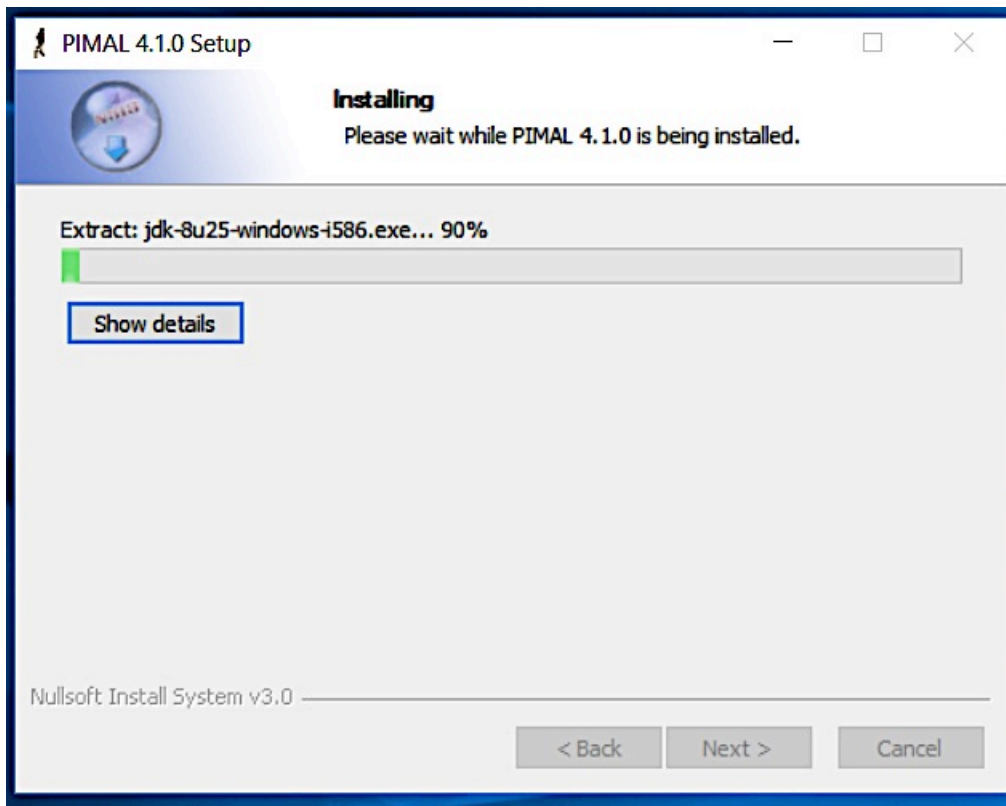


Figure 5 PIMAL Installation Process

Note: If needed, the PIMAL installer will install or update Java components as necessary. This may add to installation time, but is required to run the Java-based PIMAL application.

Step 5. After the PIMAL application itself is installed, two more programs must be installed alongside PIMAL. If those programs are already present on the computer, those steps are skipped automatically; otherwise, the installers for those programs will start.

The first of those installers is the Java Development Kit (JDK). In the Java window, select *Next* to start the installation of the JDK.

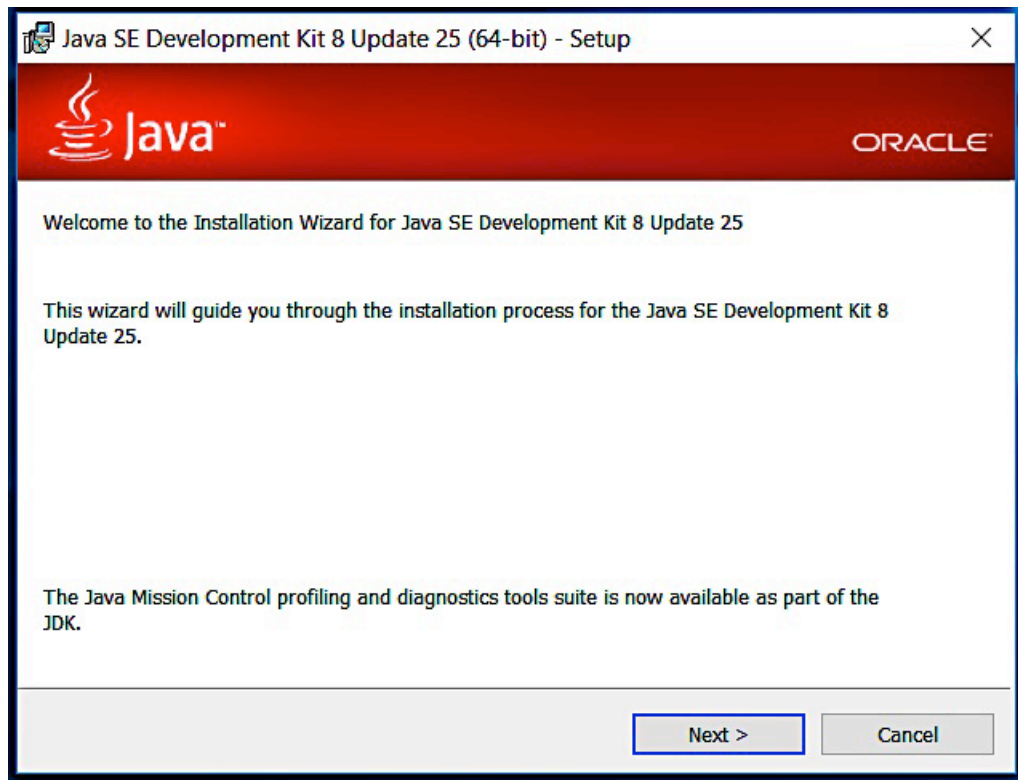


Figure 6 Start JDK Installation

Step 6. On the next screen, one can choose which components of the JDK should be installed. The requirements for PIMAL are pre-selected. Select *Next* to continue.

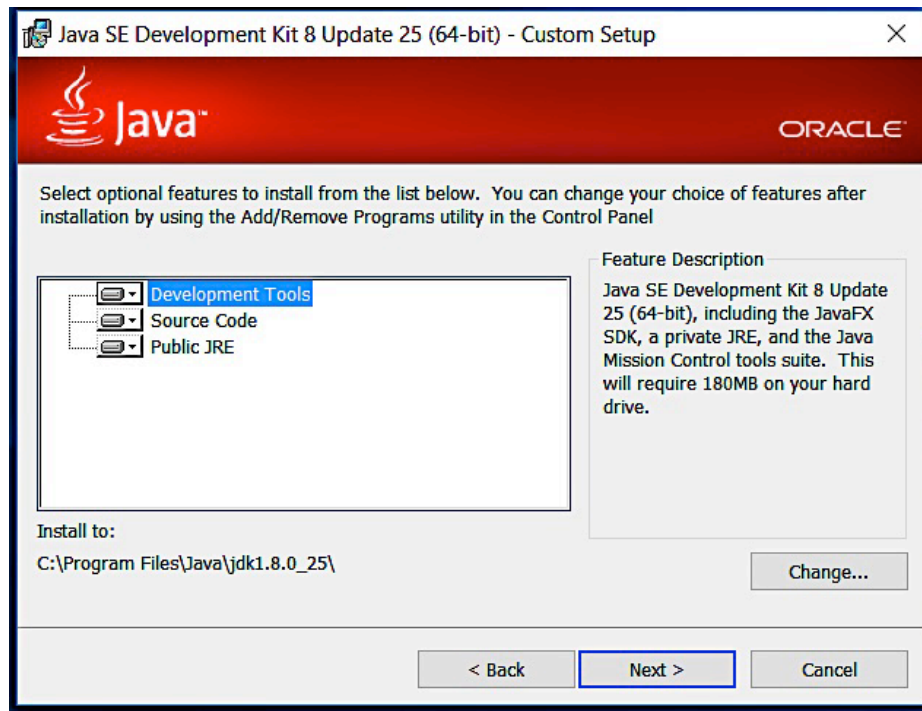


Figure 7 JDK Custom Installation

Setup Step 7. The JDK installer is extracted.

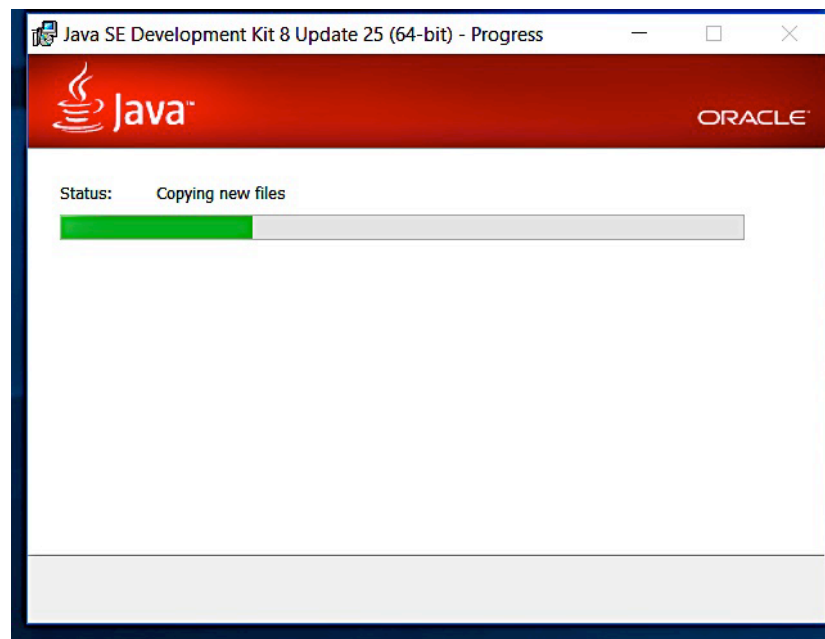


Figure 8 JDK Installer Extraction

Step 8. Select the Destination folder of the JDK or keep the default one. Begin the installation by selecting *Next*.

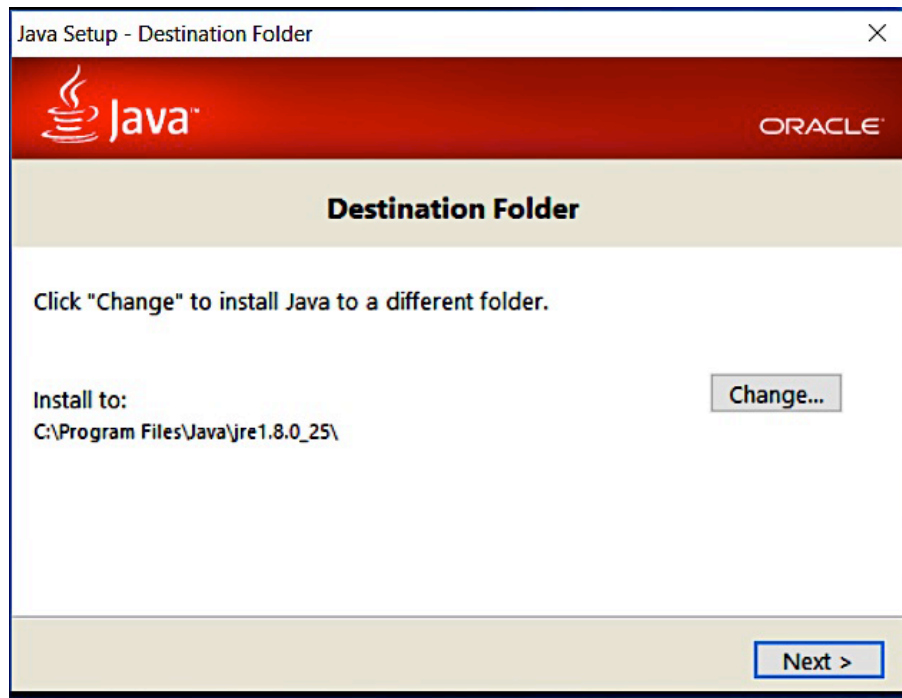


Figure 9 Select Destination Folder for JDK

Step 9. The JDK installer installs the selected components.



Figure 10 JDK Installation

Step 10. After successful installation of the JDK, select *Close* to finish this step.



Figure 11 JDK Installation Complete

Step 11. PIMAL also requires Java 3D™. If Java 3D™ is not already installed on the system, then the PIMAL installer will install it in this step.

Review the license agreement and click *Accept* to begin the installation of Java 3D™.

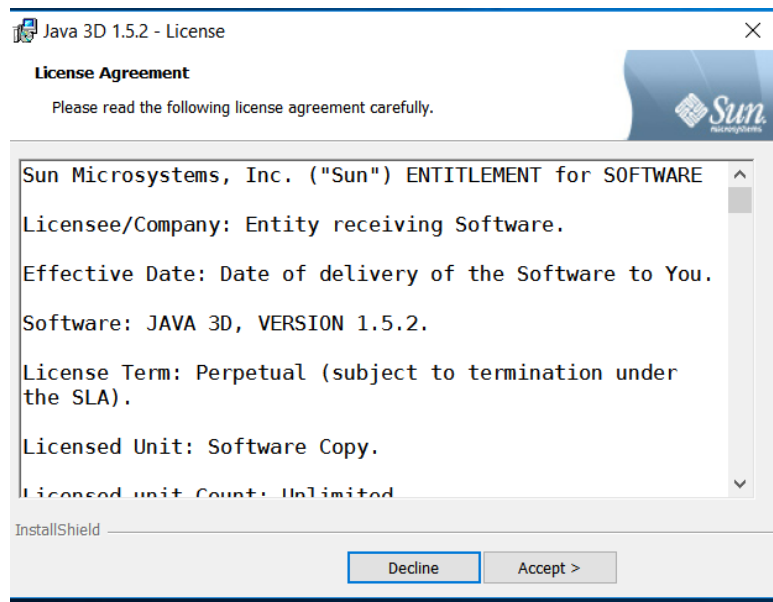


Figure 12 Start Java 3D™ Installation

Step 12. The Java 3D™ installer looks for, and installs in, the same directory as the JDK. Begin the installation into that directory by selecting *Install*.

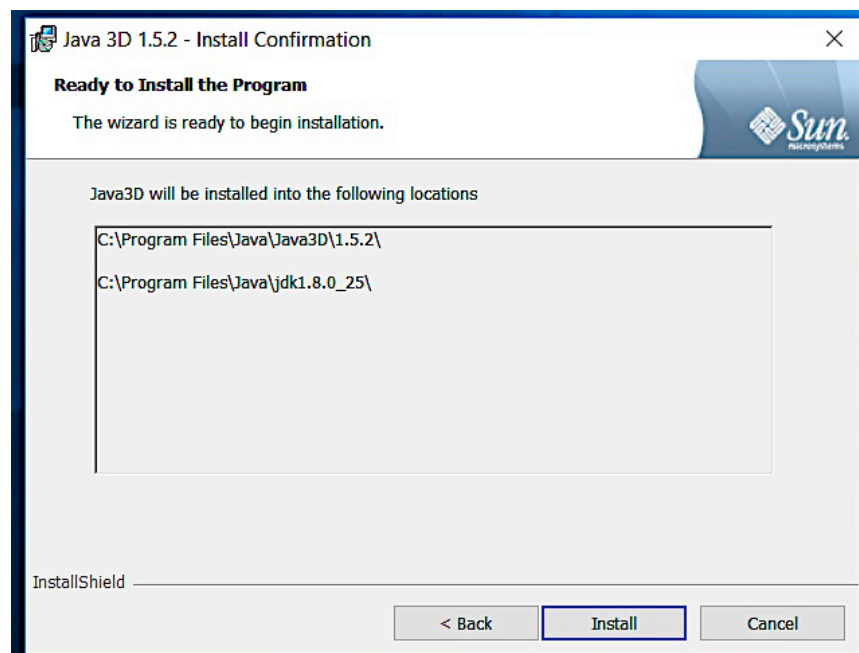


Figure 13 Java 3D™ Installation Confirmation

Step 13. Once the Java 3D™ installer has completed, select *Finish*.

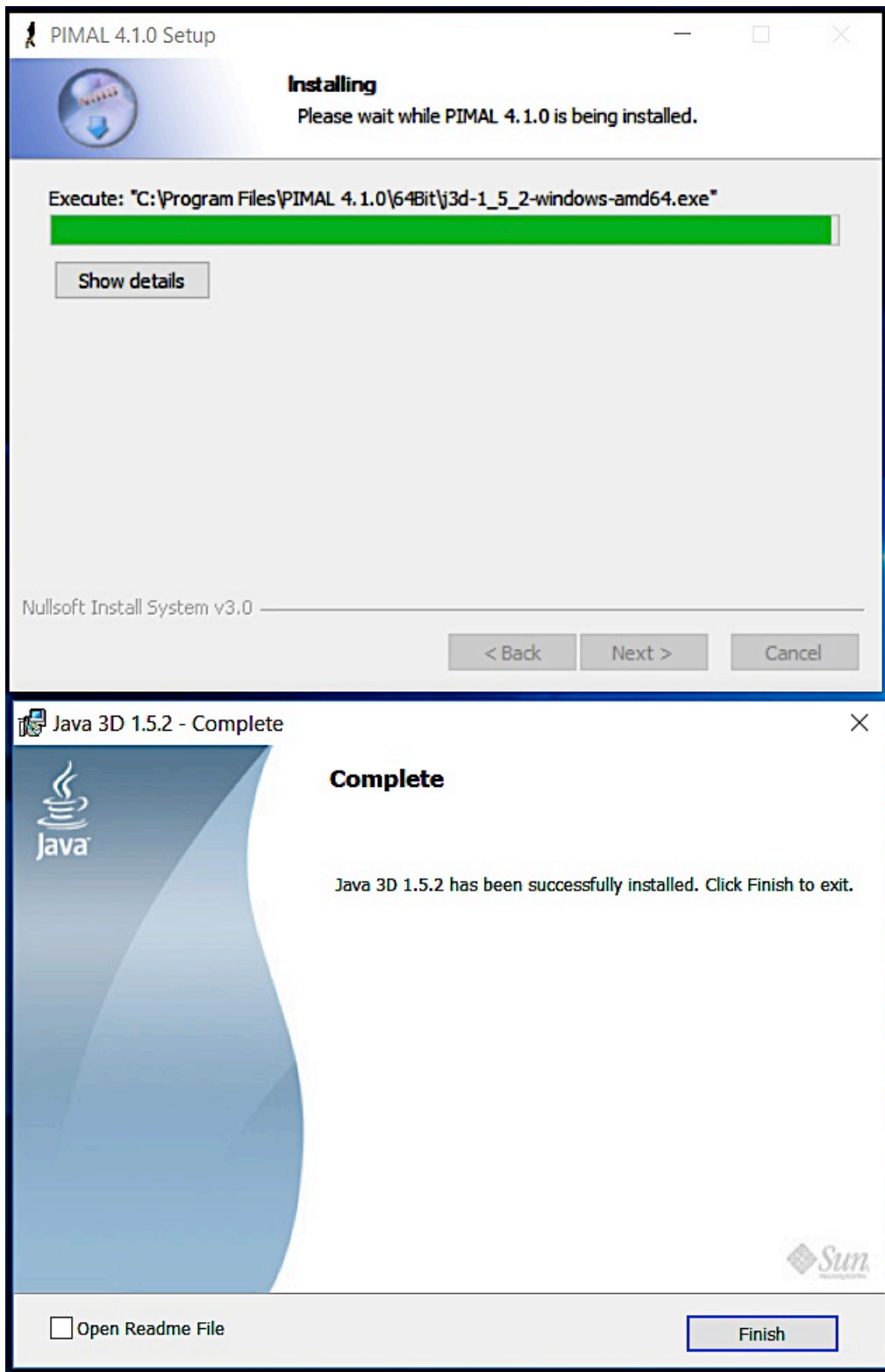


Figure 14 Java 3D™ Installation Complete

Step 14. This also completes the PIMAL installation. Click *Next* to proceed.

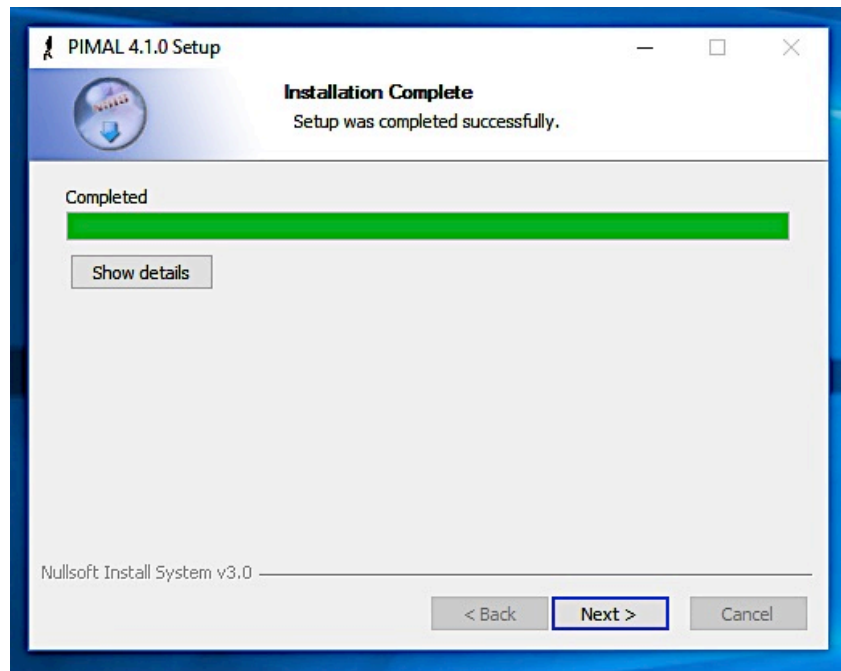


Figure 15 PIMAL Installation Complete

Step 15. Close the installer by selecting *Finish*.

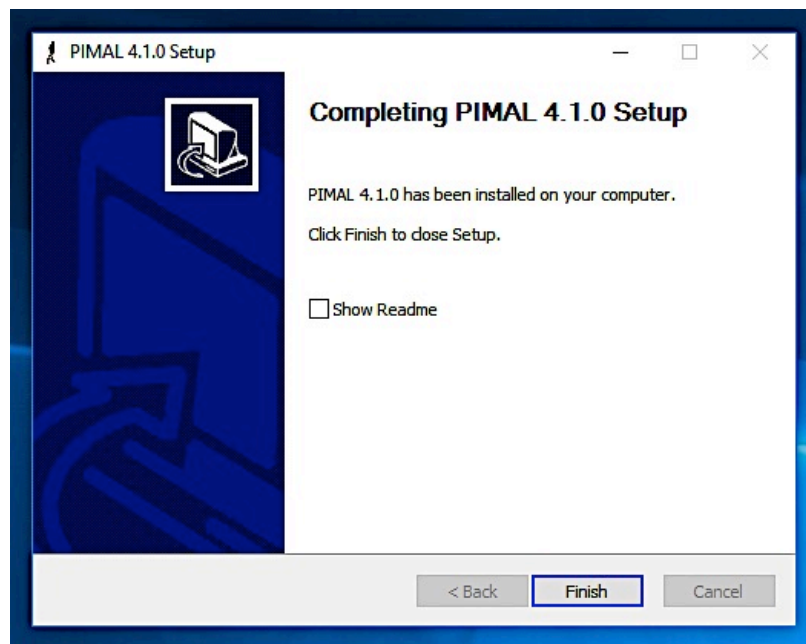


Figure 16 Close PIMAL Setup Wizard

3.2 Configuration of PIMAL

Before using PIMAL for the first time, the user must input a few customization settings. After a successful installation, double click the PIMAL icon that was created on the Windows® Desktop. PIMAL starts with the basic screen, as shown in Figure 17.

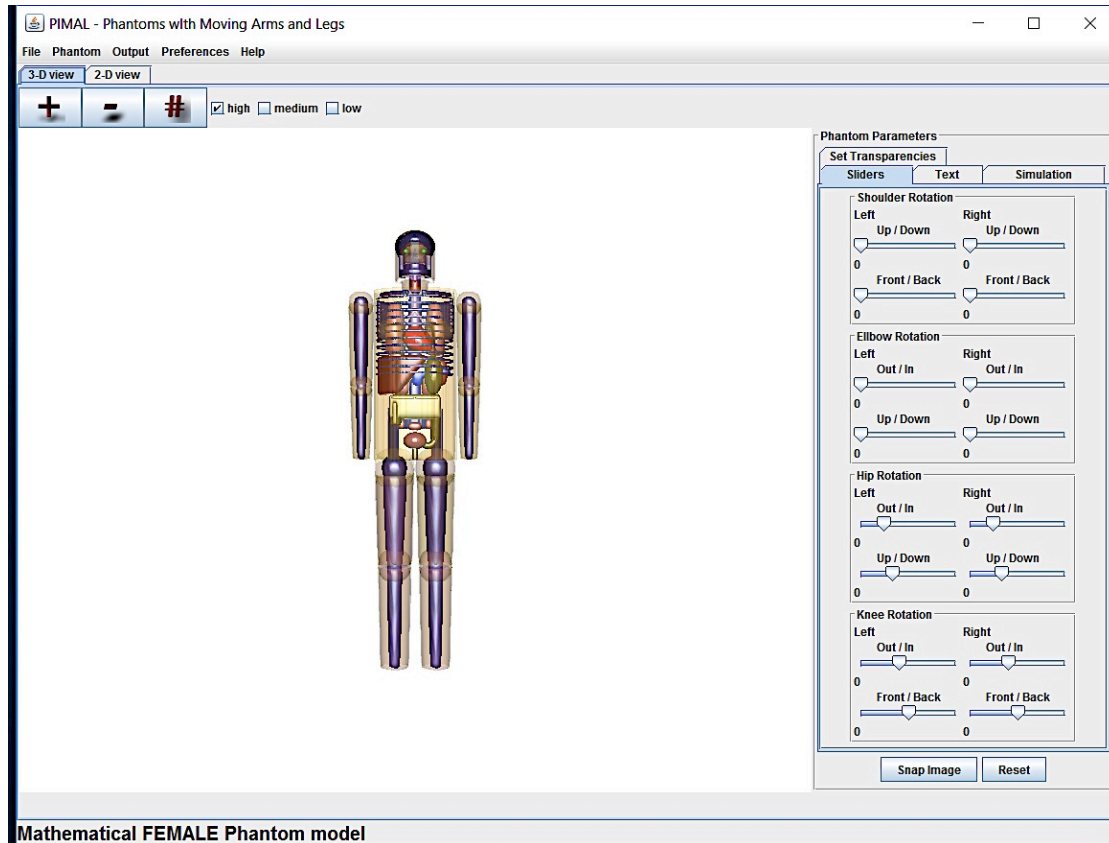


Figure 17. PIMAL After Installation

3.2.1 Setting the Working Directory

The user must define an accessible local working directory to save PIMAL and MCNP® files.

To do so, navigate to the PIMAL toolbar and select *Preferences > Set Working Directory*.

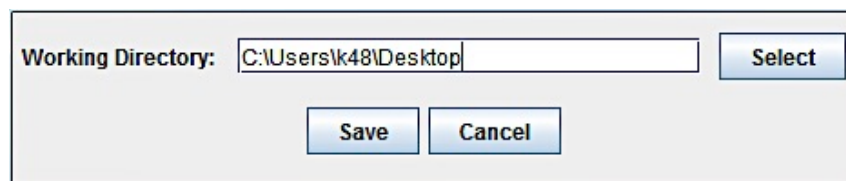


Figure 18 Working Directory Window

Click *Select*. In the resulting popup window, navigate to the folder where the files are to be saved. It is recommended that this working directory be a location where the user has read/write permissions.

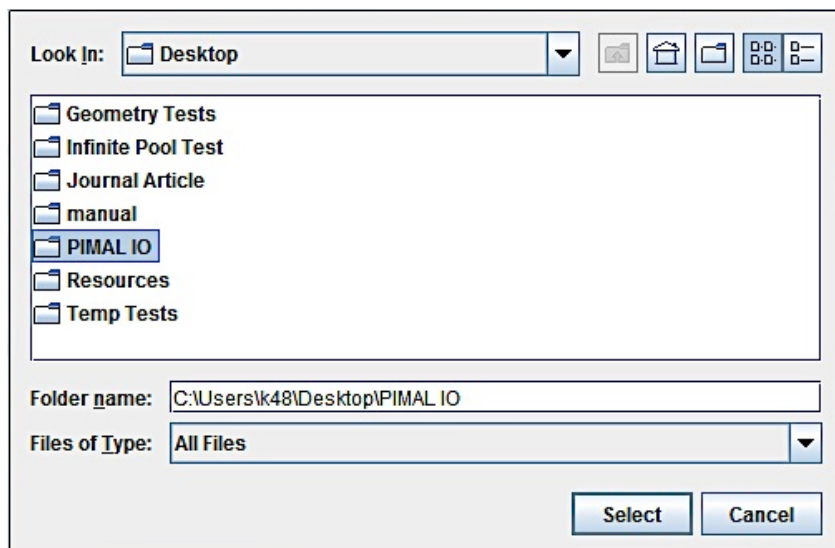


Figure 19 Second Working Directory Window

Click on the designated destination folder and press *Select*. Then click *Save* on the previous window (see Figure 18). The working directory folder is now used as the default save folder for PIMAL configurations and MCNP® runtime files.

3.2.2 Setting the Path for MCNP® Executable

The path to the MCNP® executable directory must be set in PIMAL so that MCNP® can be called from within PIMAL.

Note: PIMAL assumes that MCNP® has already been installed on the computer system. If MCNP® has not yet been installed, please request the code through appropriate channels via the Radiation Safety Information Computational Center (<https://rsicc.ornl.gov>). MCNP® is not mandatory for using the PIMAL GUI (e.g., articulating limbs/positions), but radiation transport is not possible without the presence of the MCNP® software.

First, specify the location of the MCNP® executable. On the PIMAL toolbar, select *Preferences* > *Set Path* for MCNP® Executable. The MCNP® executable pathway can be set by one of two ways; (1) entered directly in the *Executable* line (see Figure 20), or (2) by selecting the version of MCNP® using the *Select* button (see Figure 21).

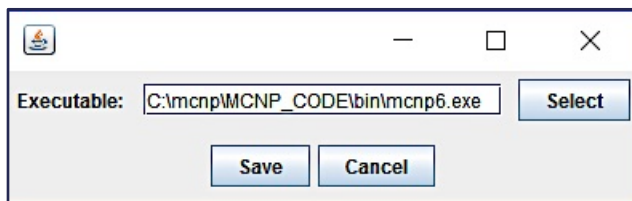


Figure 20 MCNP® Executable Window

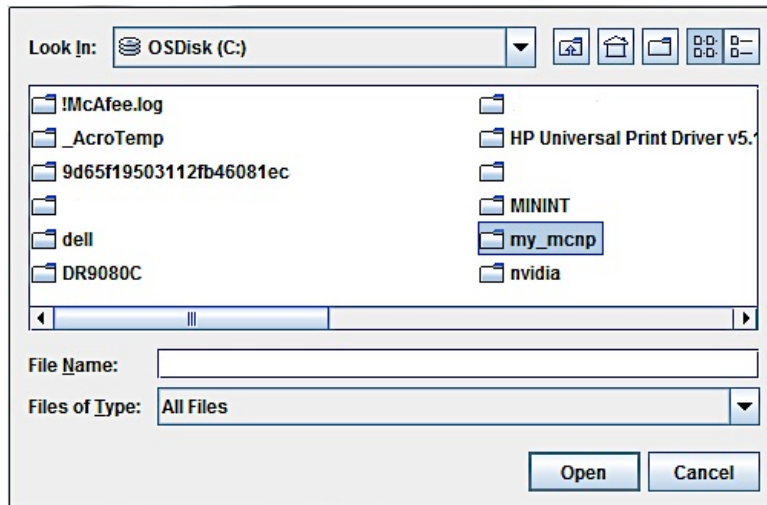


Figure 21 MCNP® Executable Path Selection

If the MCNP® installation was performed as described in the MCNP® manual, MCNP® is installed within a folder named *my_mcnp* on disk drive C:.

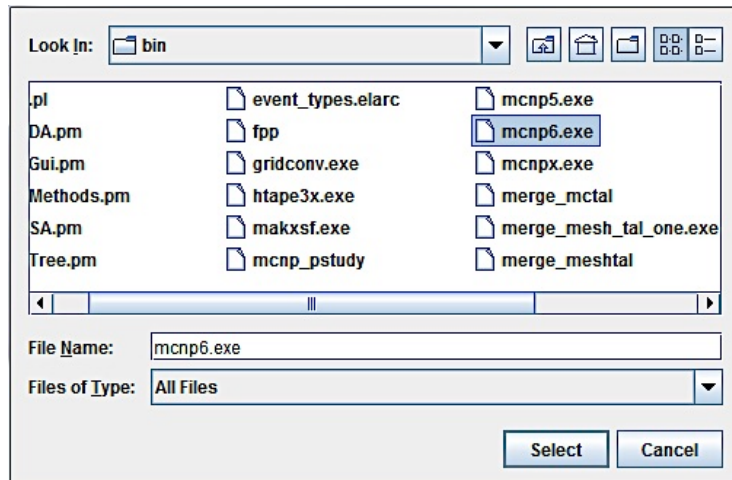


Figure 22 Location of MCNP6® Executable

Navigate into the *my_mcnp* or the user-defined MCNP® folder and highlight the MCNP® executable, (e.g., C:\my_mcnp\MCNP_CODE\bin\mcnp6.exe). Press *Select*.

4 WORKSPACE

Once the installation process has been completed and the pathways have been set, PIMAL is ready for use. The GUI permits easy customization and display of the phantom. In the following sections, the GUI overview, as well as camera controls and other functionalities in PIMAL, will be discussed.

Warning: Breaking the physical limitations of the phantom has the likely effect of causing fatal errors in MCNP®. Please do not overlap one portion of the phantom with another (e.g., impale the head with the fist, make legs or arms intersect). Treat PIMAL with care.

4.1 GUI Overview

A screenshot of the PIMAL GUI is given in Figure 23, with key features of the interface labeled.

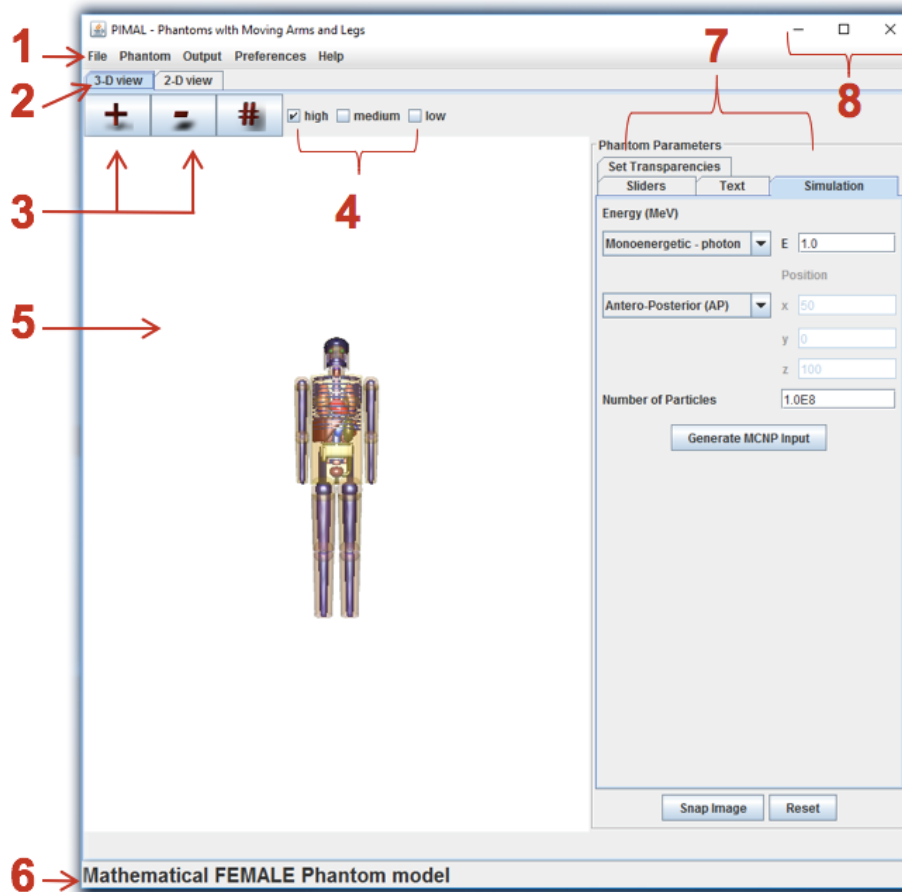


Figure 23 PIMAL Graphical User Interface

- | | |
|--------------------------------------|--------------------------------------|
| 1 - PIMAL Toolbar | 5 - Java 3D™ Environment |
| 2 - 2D & 3D View Tabs | 6 - PIMAL Status Bar |
| 3 - Zoom In / Zoom Out / Coordinates | 7 - Phantom Parameters Sidebar |
| 4 - Phantom Resolution Quality | 8 - Minimize/ Maximize/ Close Button |

4.2 Camera Controls

Rotation and zooming of the PIMAL phantom is controlled entirely via computer mouse function via the following mouse click/drag mechanisms:

- Mouse left click and drag: Camera rotation
- Mouse right click and drag: Camera translation in that direction
- Mouse middle click and drag: Camera zoom forward and backward
- Mouse middle scroll: Camera zoom forward and backward

4.3 Using the Sliders window

If the sliders pane is not open on the sidebar, click on the *Sliders* tab to open it. Clicking and dragging a slider for each labeled rotation moves the respective appendage. Experiment with each of the 16 sliders to become familiar with their operation.

To start, each slider is positioned at zero. Some sliders can be moved only in the positive direction, while others can move in both positive and negative directions. Click *Reset* to reset all sliders and the phantom posture

Figure 24 shows the default stance of the phantom, with all sliders at the zero position.

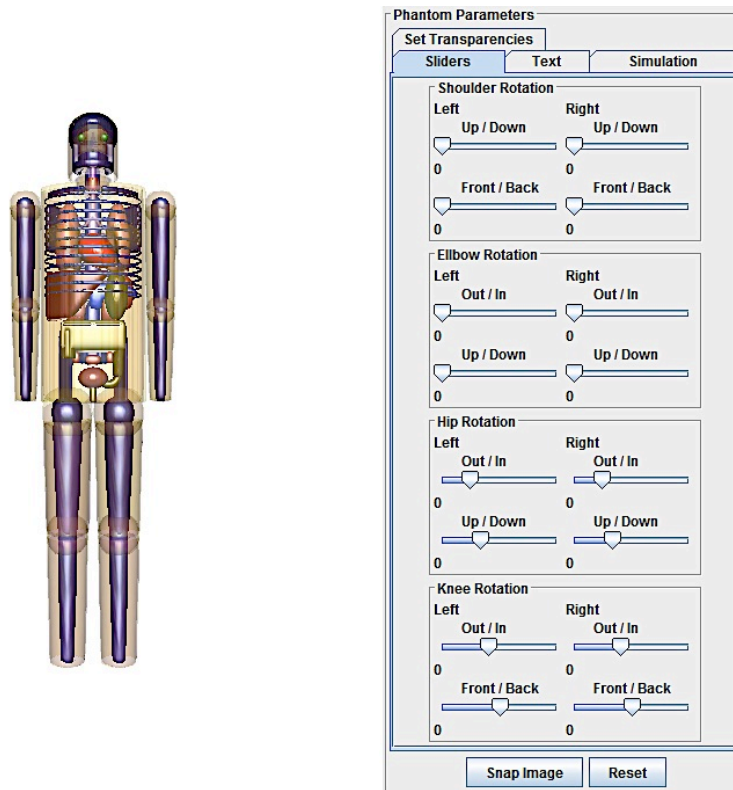


Figure 24 Default PIMAL Stance - Sliders

Figure 25 shows the result of moving the left shoulder rotation slider to 90 degrees; note the changed stance.

Note: The range of motion for the sliders is summarized in Appendix B.

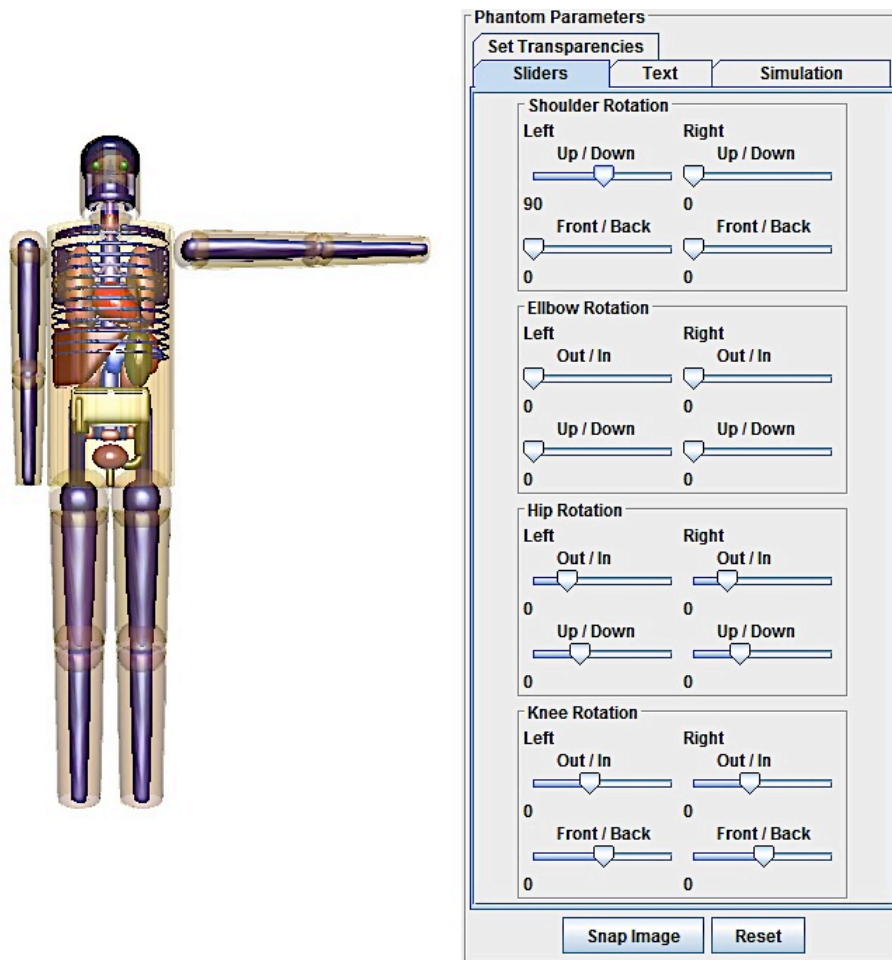


Figure 25 PIMAL with Left Shoulder Rotated 90 Degrees - Sliders

4.4 Using the Text window

Figure 26 shows the default PIMAL stance with the text window open in the sidebar. To open the sidebar in text mode, click on the *Text* tab. Specific rotation of one or more appendages may be obtained by entering the desired value(s) in the text input boxes.

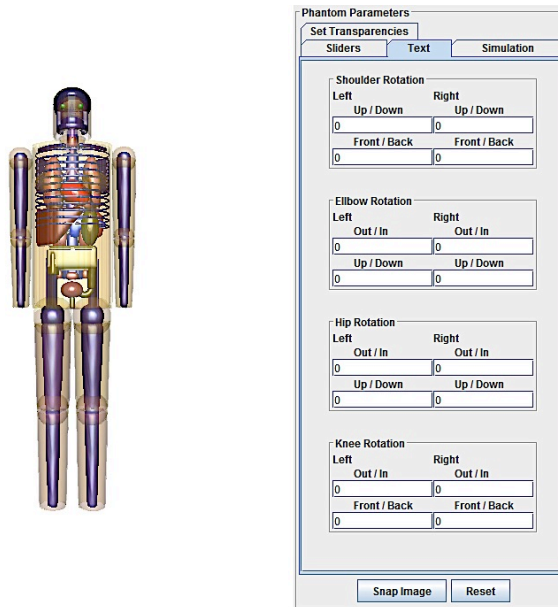


Figure 26 Default PIMAL Stance - Text

Figure 27 shows a 90-degree rotation of the left shoulder. This rotation is obtained by entering “90” into the left shoulder rotation box.

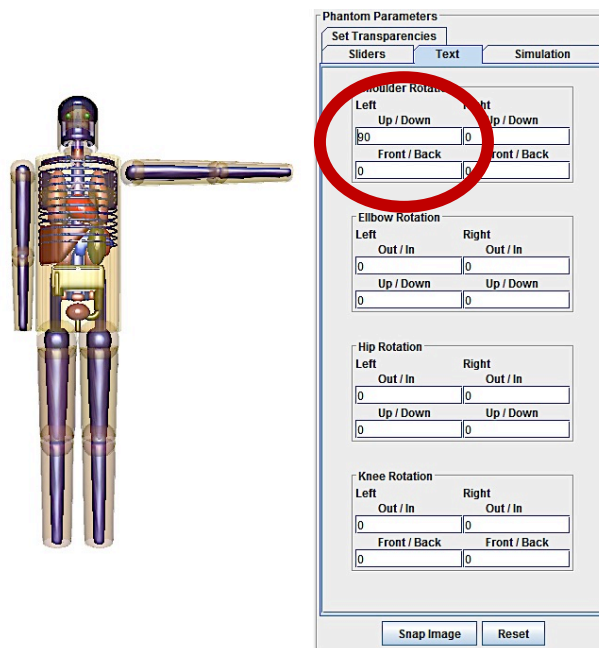


Figure 27 PIMAL with Left Shoulder Rotated 90 Degrees - Text

4.5 Setting Phantom Transparencies

To open the transparency pane on the sidebar, select the *Set Transparencies* tab. When the box is checked for each tissue/organ, the tissue/organ becomes transparent in the Java 3D™ environment. Note that the bones, lungs, and heart are transparent in the right-hand image.

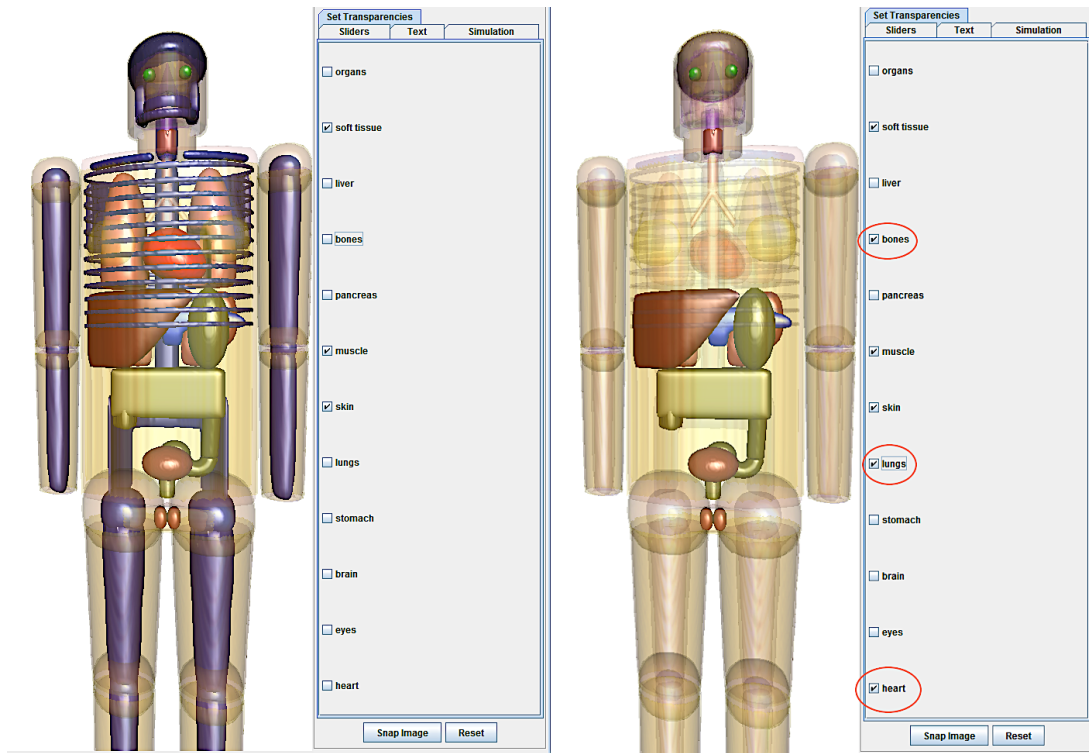


Figure 28 Checking the Bones, Lungs, and Heart Transparency Boxes

Unchecking the box for each tissue/organ makes it opaque. These transparencies can be reset to the default setting through the phantom reset button.

4.6 Resetting the Phantom

The easiest way to reset the phantom to its initial position is to select the reset button located in the bottom right corner of the GUI. (see Figure 29) All appendage rotations are returned to zero, the transparencies of tissues and organs are returned to the default settings, and the camera is returned to the initial position.

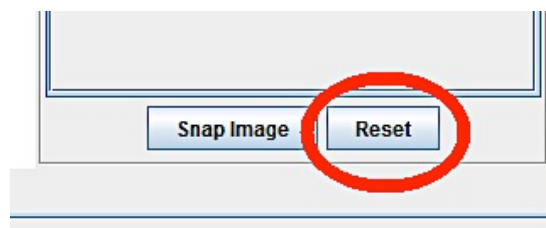


Figure 29 Phantom and Reset Button

4.7 Two-Dimensional View

Another useful feature of PIMAL is the ability to create cross-sectional, two-dimensional (2D) views of the phantom. The dropdown menu seen at the top right corner of Figure 30 defines the different planes to be viewed. The text entry boxes control the range of what is drawn in a certain direction. The cut plane slider allows the user to move the cross-sectional view in the direction perpendicular to the view plane (e.g., in Figure 30, the 2D views are in the xz plane and the slider moves the camera in the y-direction). Finally, the resolution controls the detail of the drawing.

After all changes are made to the settings, the *Redraw* button must be selected to apply the changes. The *Reset* button will return the 2D view to its default settings.

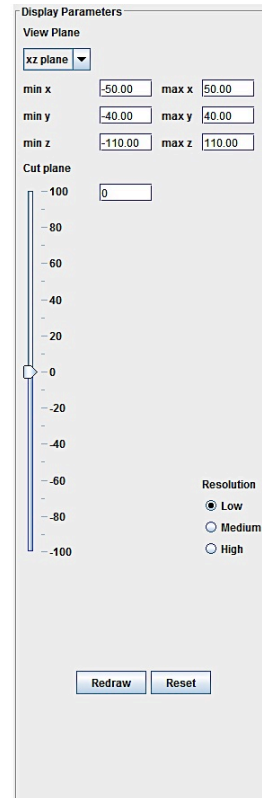
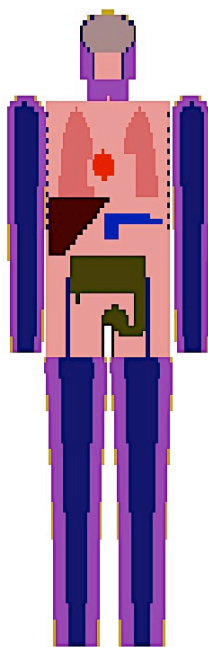


Figure 30 2D View Workspace

4.8 Saving Current Configuration

See Generating MCNP® Inputs, Section 5.4.

4.9 Recalling Past Configurations

After a PIMAL MCNP® input has been saved, the settings used in the input file can be reopened (e.g., source definition, appendage rotations). To do so, click on *File > Open Input* in the toolbar. (see Figure 31) In the generated popup window, navigate to the directory containing the input file to be reopened and select *Open*.

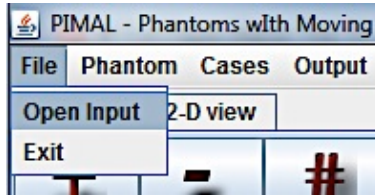


Figure 31 Opening PIMAL Input

4.10 Exiting PIMAL

To safely exit the PIMAL software, navigate to the toolbar and select *File > Exit*. (see Figure 31) Be aware that clicking *Exit* will quit PIMAL without saving the phantom configuration. If you wish to save your configuration, do so before exiting PIMAL.

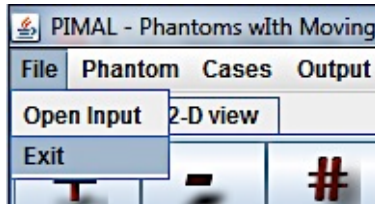


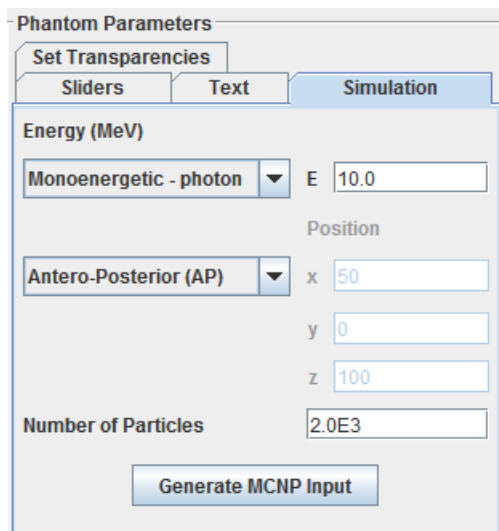
Figure 32 Exiting PIMAL through Toolbar

5 GENERATING MCNP® INPUTS

Once the positioning of the phantom is complete, the next step of the process is to generate the MCNP® input file. This includes defining a source, allowing PIMAL to generate the file, displaying source points for source validation, and saving the input. Custom source creation is introduced in this section (it is discussed more thoroughly in the Tutorials, Section 7). The majority of this section will deal with the simulation tab on the phantom parameters sidebar (see Figure 33).

5.1 PIMAL Built-in Source Settings

PIMAL contains numerous built-in sources for user convenience under the *Simulations* tab (see Figure 33).



The image shows a software interface titled "Phantom Parameters". It has three tabs: "Set Transparencies", "Sliders", and "Simulation". The "Simulation" tab is selected. Inside this tab, there are several input fields and a button. Under "Energy (MeV)", there is a dropdown menu set to "Monoenergetic - photon" and a text box with "10.0". Below this, under "Position", there are three text boxes for "x", "y", and "z", with values "50", "0", and "100" respectively. At the bottom, there is a text box for "Number of Particles" with the value "2.0E3". A button labeled "Generate MCNP Input" is located at the bottom center of the simulation tab.

Figure 33 Depiction of Simulation Tab on Sidebar

Source energy options are the following:

- **Monoenergetic photon/neutron:** Source energy defined in text box (MeV) for radionuclides were taken from ICRP Publication 107 nuclear decay data [8]:
- **I-131:** Iodine-131 source spectrum
- **Co-60:** Cobalt-60 source spectrum
- **Cs-134:** Cesium-134 source spectrum
- **X-ray (60-120) kVp:** X-ray source spectrum from machines running at 60-120 kV peak voltages
- **AmBe/PuBe neutron source:** AmBe/PuBe energy spectrum (utilizes the n,p reaction)

The *Energy (MeV)* dropdown menu is for the selection of a source energy or energy spectrum. The second dropdown menu gives options for the source geometry. These source geometry options are

- **Antero-posterior (AP):** Particles enter the phantom through the front (anterior) surface and exit through the back (posterior) surface.
- **Postero-anterior (PA):** Particles enter the phantom through the back (posterior) surface and exit through the front (anterior) surface.
- **Left/right lateral (LLAT/RLAT):** Particles enter the phantom through the left/right lateral surface.
- **Point source:** The point source of particles is defined by the position to be entered in the text boxes.
- **Isotropic:** The source is defined on a spherical surface surrounding the phantom (surface 338 for the female phantom and surface 294 for the male phantom).
- **Internal sources:** Source defined within specified organs.

The last entry is for specifying the number of particles to run in the MCNP® simulation. This value can be edited in the next step or in a text editor by looking for the **NPS** (number of particles) line at the bottom of the MCNP® input file. The NPS required for each simulation depends on the source and receptor geometry. The required statistics for a Monte Carlo problem to converge is unique to each modeled source and receptor. Users are strongly recommended to consult the MCNP® manual [9].

5.2 Generating MCNP® Input

To generate the MCNP® input file, select the *Generate MCNP Input* button shown at the bottom of Figure 33. Figure 34 shows an example MCNP® input window that resulted from selecting the *Generate MCNP Input* button. The contents of the MCNP® input file may be edited through the input window using the built-in text editor. Changes made to the input file will be saved and used from this point.

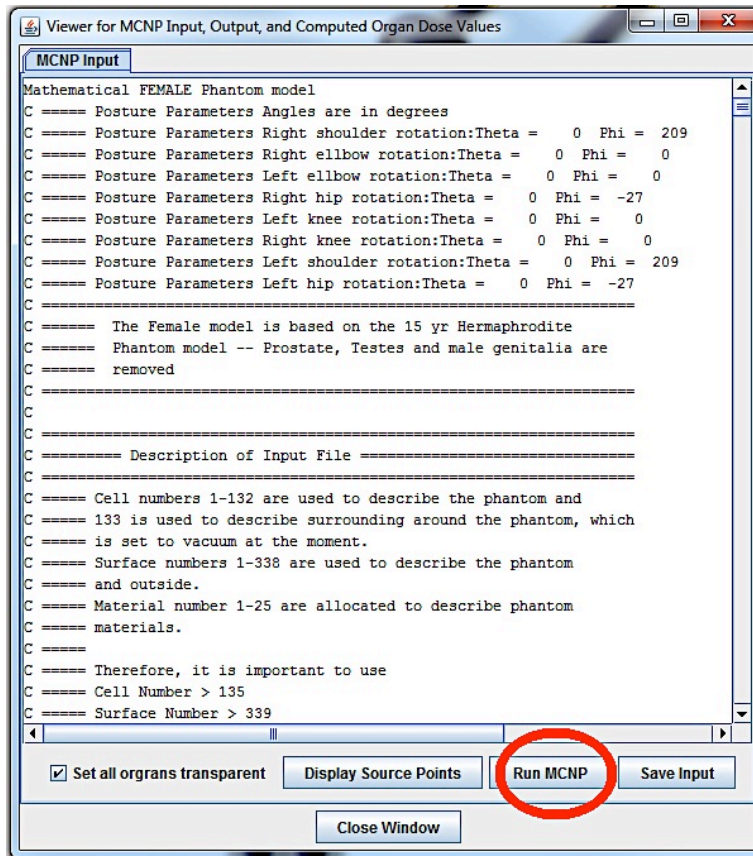


Figure 34 Generate MCNP® Input Window

5.3 Displaying Source Points

Displaying the source points is a convenient way to visualize the geometry of the source in and around the phantom (see Figure 35). Selecting *Display Source Points* will initiate the process. MCNP® runs and determines the location of the source points. After MCNP® finishes, the Java 3D™ environment refreshes and the source points are displayed.

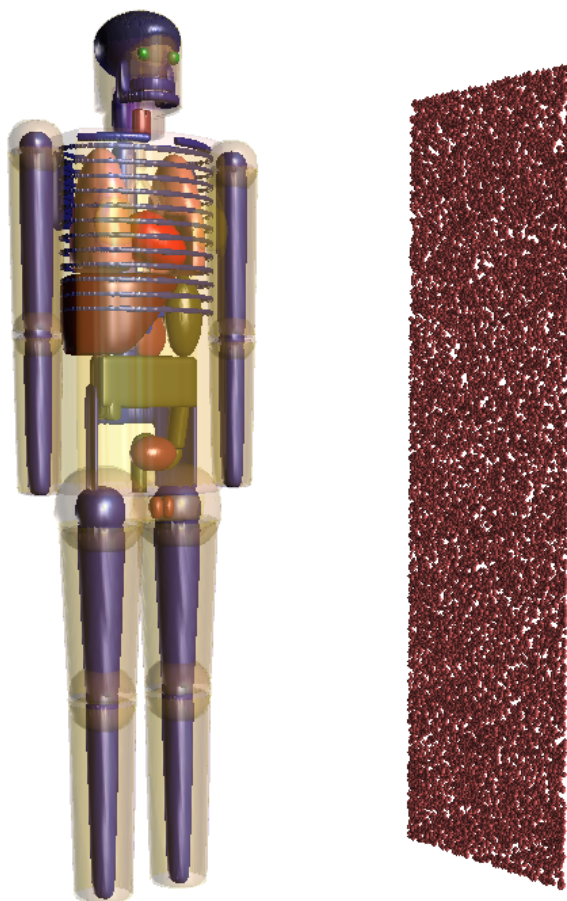


Figure 35 Source Point Display of LLAT Geometry

Adjustable settings for source display are as follows:

- **Source Display Number:** The number of source points may be set and changed in *Preferences > Set Source Display Number*. Your computer hardware may limit the number of points that can be displayed.
- **Source Display Color:** The color of the displayed source points may be set and changed in *Preferences > Set Source Color*
- **Organ Transparency:** When checked, *Set all organs transparent*, seen in Figure 36, results in all phantom transparencies being turned on for the source display. Transparent organs are essential for viewing internal sources.

5.4 Saving Input

To save an MCNP® input, navigate to the toolbar shown at the bottom of the input screen (see Figures 34 and 36). Select *Save Input* to open the save dialog.



Figure 36 Setting Transparent Organs and Save Input Location

In this window, input the desired file name and select save to complete the process.

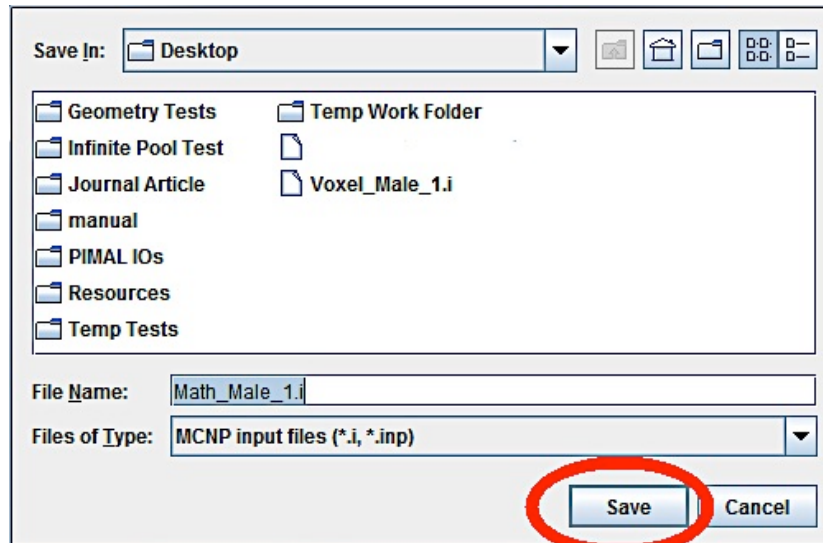


Figure 37 Save Input Window

5.5 Entering Custom Source Configurations

PIMAL contains a selection of predefined internal and external sources, but additional sources may be needed. In advanced cases, a source may be defined manually outside the PIMAL interface and run natively from the MCNP® command line. Note that external customization is recommended only for advanced MCNP® users.

The steps for entering a custom source are outlined below; these steps are detailed thoroughly in the Water Submersion Tutorial (Section 7.3):

- (1) Save the MCNP® input file and open the new, custom source file in a text editor, or edit within the *Generate MCNP Input window* using the built-in text editor.
- (2) Make changes to the Materials card (addition of materials).
- (3) Make changes to Cell/Surface cards with inclusion of materials.
- (4) Edit the Source definition (SDEF).
- (5) If you are editing within PIMAL, display the source points to aid in validation.
- (6) Save the new source input file.

6 RUNNING MCNP®

An MCNP® input file has been created through PIMAL based on user-provided settings. The next step is to run MCNP® using the new input file and extract dose tallies. In this section, the options for running a PIMAL-generated MCNP® input file and viewing the organ doses from the MCNP® output file are presented.

6.1 Running MCNP® through PIMAL

MCNP® may be run through PIMAL without having to use the MCNP® command line. To start, generate the MCNP® input file as shown in Section 5.2.

From the popup menu, select *Run MCNP* (see Figure 34).

While MCNP® runs in the background, the MCNP® output is shown in the *MCNP Screen Output* tab. (see Figure 38) Until MCNP® has fully completed its execution, the only way to abort the run is by closing the window, regenerating the MCNP® input, and selecting *Run MCNP* again. At that point, the option to display source points becomes available again.

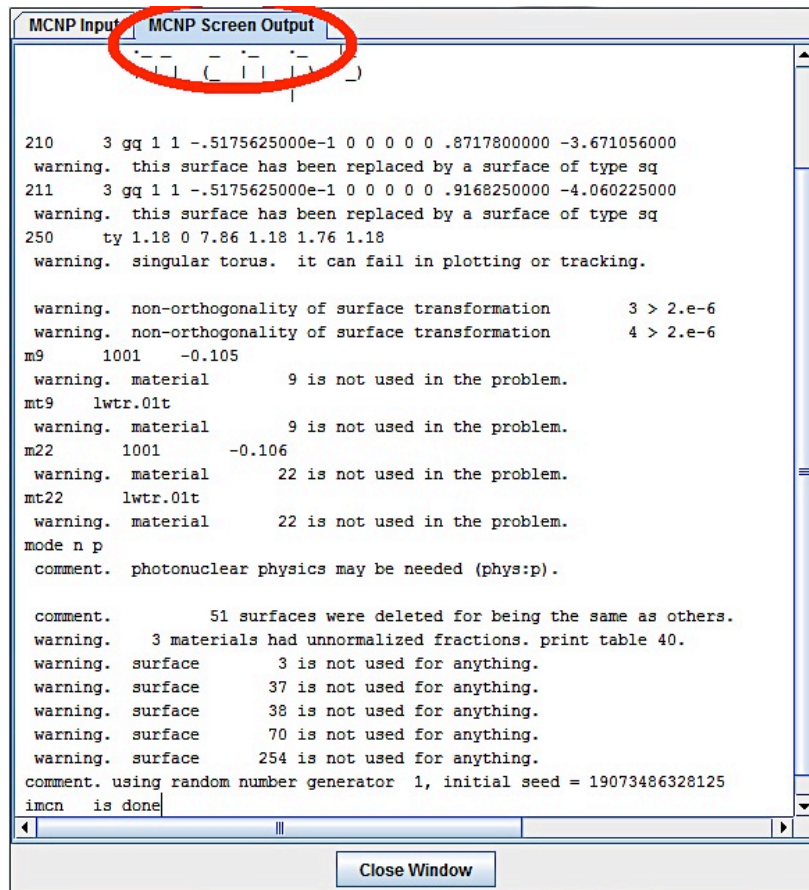
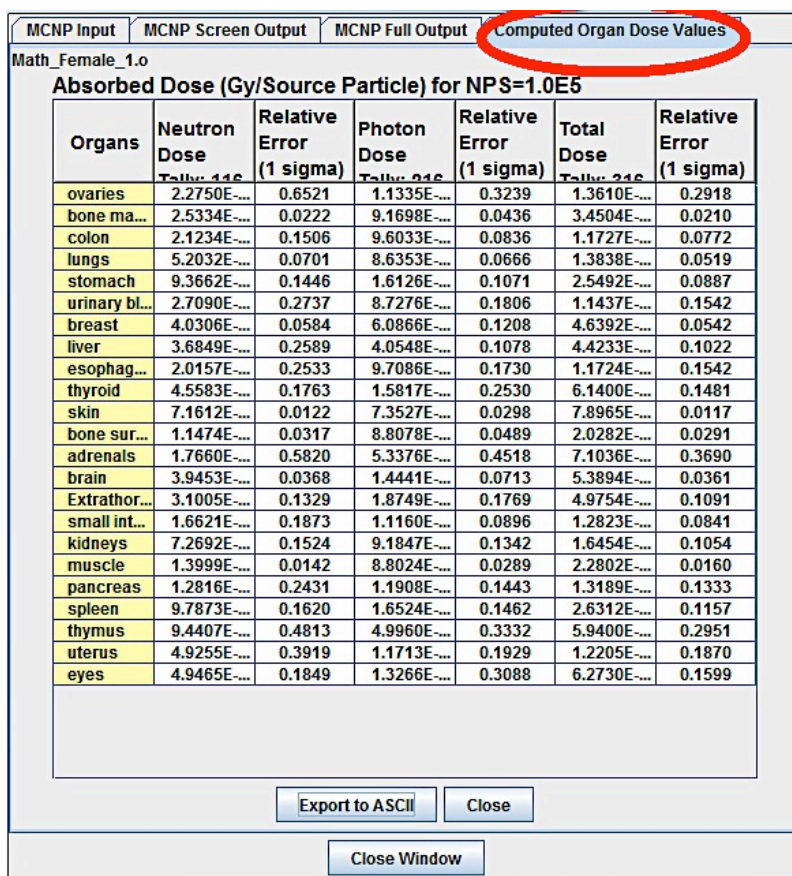


Figure 38 MCNP® Screen Output

The organ dose chart is created automatically when the MCNP® run is finished. See Section 6.3, Viewing Organ Dose, for more details on this output table. The full “.o” output file can also be viewed in the third tab, *MCNP Full Output*.



Math_Female_1.o

Absorbed Dose (Gy/Source Particle) for NPS=1.0E5

Organs	Neutron Dose Table 116	Relative Error (1 sigma)	Photon Dose Table 216	Relative Error (1 sigma)	Total Dose Table 216	Relative Error (1 sigma)
ovaries	2.2750E-...	0.6521	1.1335E-...	0.3239	1.3610E-...	0.2918
bone ma...	2.5334E-...	0.0222	9.1698E-...	0.0436	3.4504E-...	0.0210
colon	2.1234E-...	0.1506	9.6033E-...	0.0836	1.1727E-...	0.0772
lungs	5.2032E-...	0.0701	8.6353E-...	0.0666	1.3838E-...	0.0519
stomach	9.3662E-...	0.1446	1.6126E-...	0.1071	2.5492E-...	0.0887
urinary bl...	2.7090E-...	0.2737	8.7276E-...	0.1806	1.1437E-...	0.1542
breast	4.0306E-...	0.0584	6.0866E-...	0.1208	4.6392E-...	0.0542
liver	3.6849E-...	0.2589	4.0548E-...	0.1078	4.4233E-...	0.1022
esophag...	2.0157E-...	0.2533	9.7086E-...	0.1730	1.1724E-...	0.1542
thyroid	4.5583E-...	0.1763	1.5817E-...	0.2530	6.1400E-...	0.1481
skin	7.1612E-...	0.0122	7.3527E-...	0.0298	7.8965E-...	0.0117
bone sur...	1.1474E-...	0.0317	8.8078E-...	0.0489	2.0282E-...	0.0291
adrenals	1.7660E-...	0.5820	5.3376E-...	0.4518	7.1036E-...	0.3690
brain	3.9453E-...	0.0368	1.4441E-...	0.0713	5.3894E-...	0.0361
Extrathor...	3.1005E-...	0.1329	1.8749E-...	0.1769	4.9754E-...	0.1091
small int...	1.6621E-...	0.1873	1.1160E-...	0.0896	1.2823E-...	0.0841
kidneys	7.2692E-...	0.1524	9.1847E-...	0.1342	1.6454E-...	0.1054
muscle	1.3999E-...	0.0142	8.8024E-...	0.0289	2.2802E-...	0.0160
pancreas	1.2816E-...	0.2431	1.1908E-...	0.1443	1.3189E-...	0.1333
spleen	9.7873E-...	0.1620	1.6524E-...	0.1462	2.6312E-...	0.1157
thymus	9.4407E-...	0.4813	4.9960E-...	0.3332	5.9400E-...	0.2951
uterus	4.9255E-...	0.3919	1.1713E-...	0.1929	1.2205E-...	0.1870
eyes	4.9465E-...	0.1849	1.3266E-...	0.3088	6.2730E-...	0.1599

Export to ASCII Close

Close Window

Figure 39 Tabulated Organ Doses

Note: If fatal errors occur during the MCNP® run, the organ dose chart will not be generated, and the reason will be shown in a dialogue box. Select OK to continue. (see Figure 40)

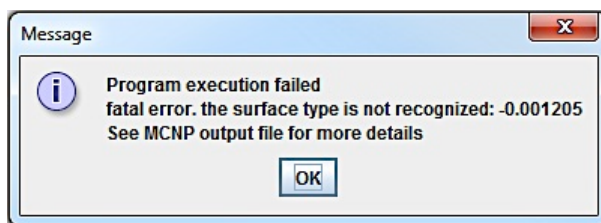


Figure 40 Fatal Error Warning

Fatal errors occur if run from the GUI natively if PIMAL is improperly positions (e.g. self-impaling position). If the user conducts modifications to the input files outside of the PIMAL GUI options independently, the user is responsible for identifying if the additional modifications create the fatal error.

6.2 Running MCNP® through the Command Prompt

Another way to run the MCNP® inputs created by PIMAL is through the computer command prompt/terminal as shown in Figure 41.

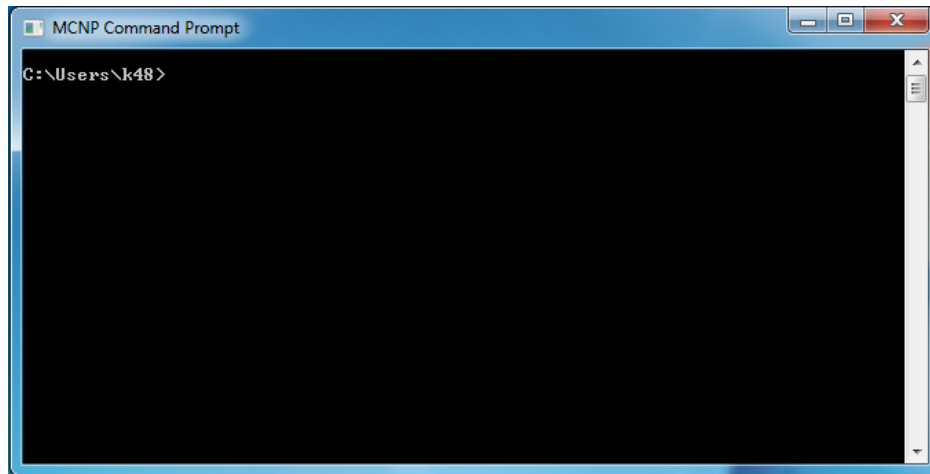


Figure 41 Command Prompt on Windows®

First, change the working directory to the folder containing the input file. In Figure 42, the folder is named *PIMAL IOs*.

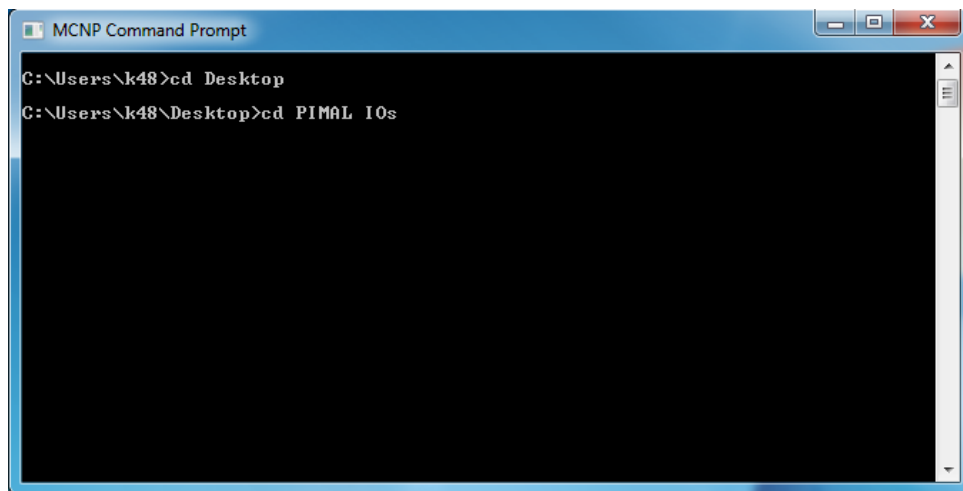
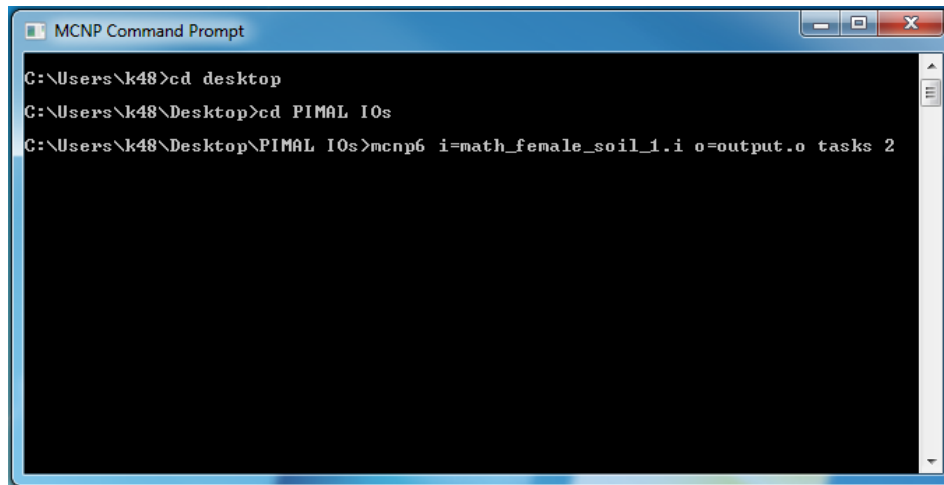


Figure 42 Changing Working Directory

PIMAL outputs were originally made to run in MCNP5®; MCNP5® is also included on the MCNP6®/MCNP6.1.1® installation disks. To ensure compatibility with all features, using MCNP6® or MCNP6.1.1® is recommended for PIMAL 4.1.0.

As seen in Figure 43, the formatting of the command is as follows:

- **MCNP6:** start off the command stating which version to use
- **i:** tells MCNP® what the input file is named (math_female_soil_1.i)
- **o:** tells MCNP® what to name the output file (output.o)
- **tasks 2:** optional specification of the number of cores to use in multiprocessing

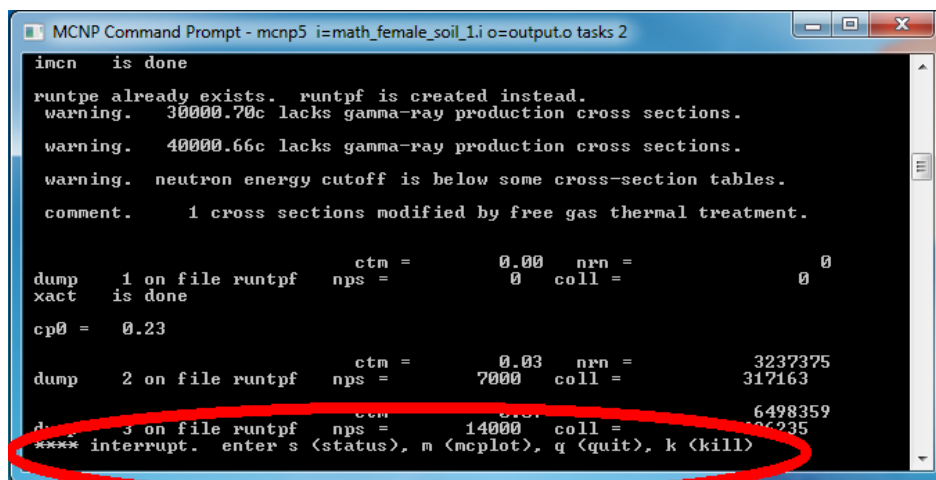


```
MCNP Command Prompt
C:\Users\k48>cd desktop
C:\Users\k48\Desktop>cd PIMAL IOs
C:\Users\k48\Desktop\PIMAL IOs>mcnp6 i=math_female_soil_1.i o=output.o tasks 2
```

Figure 43 Running the Input File

The run may be interrupted at any time by selecting *Ctrl + C*. An interrupted (paused) run is shown in Figure 44. The last line in Figure 44 shows the options that are available by entering the chosen character on the command line/terminal. The options are the following:

- **s:** check the status of the run (time used, number of particles tracked)
- **m:** plot the current tally result
- **q:** quit the execution and save the current results
- **k:** kill the execution with no results generated



```
MCNP Command Prompt - mcnp5 i=math_female_soil_1.i o=output.o tasks 2
imcn is done
runtpf already exists. runtpf is created instead.
warning. 30000.70c lacks gamma-ray production cross sections.
warning. 40000.66c lacks gamma-ray production cross sections.
warning. neutron energy cutoff is below some cross-section tables.
comment. 1 cross sections modified by free gas thermal treatment.

dump 1 on file runtpf ctn = 0.00 nrn = 0
xact is done nps = 0 coll = 0
cp0 = 0.23

dump 2 on file runtpf ctn = 0.03 nrn = 3237375
nps = 7000 coll = 317163
cp0 = 0.23

dump 3 on file runtpf ctn = 0.03 nrn = 6498359
nps = 14000 coll = 317163
cp0 = 0.23
**** interrupt. enter s <status>, m <mcplot>, q <quit>, k <kill>
```

Figure 44 Pausing the Run

6.3 Viewing Organ Dose

After the MCNP® input file runs, the MCNP® output is shown in tabular form. The tallied dose is parsed for convenience. To view the tallied dose, navigate to the PIMAL toolbar and select *Output > View Organ Dose*.

Absorbed Dose (Gy/Source Particle) for NPS=2.5E7

Organs	Photon Dose Tally: 216	Relative Error (1 sigma) Tally: 216
ovaries	5.1683E-18	0.0778
bone marrow	6.0012E-18	0.0080
colon	4.8027E-18	0.0197
lungs	5.5763E-18	0.0135
stomach	5.2059E-18	0.0300
urinary bladder	4.9299E-18	0.0377
breast	6.1668E-18	0.0216
liver	5.2679E-18	0.0174
esophagus	5.0845E-18	0.0402
thyroid	5.3600E-18	0.0735
skin	7.1396E-18	0.0064
bone surface	5.5923E-18	0.0086
adrenals	5.2758E-18	0.0724
brain	6.2817E-18	0.0172
Extrathoracic airways	5.5954E-18	0.0481
small intestine	4.9381E-18	0.0203
kidneys	5.2553E-18	0.0272
muscle	5.2566E-18	0.0056
pancreas	5.0244E-18	0.0370
spleen	5.0218E-18	0.0394
thymus	5.1751E-18	0.0582
uterus	4.9582E-18	0.0481
eyes	6.0958E-18	0.0729

Export to ASCII Close

Figure 45 Organ Dose Chart

In the output selection window, navigate to the folder containing the output files and highlight the output file. Select *Open*.

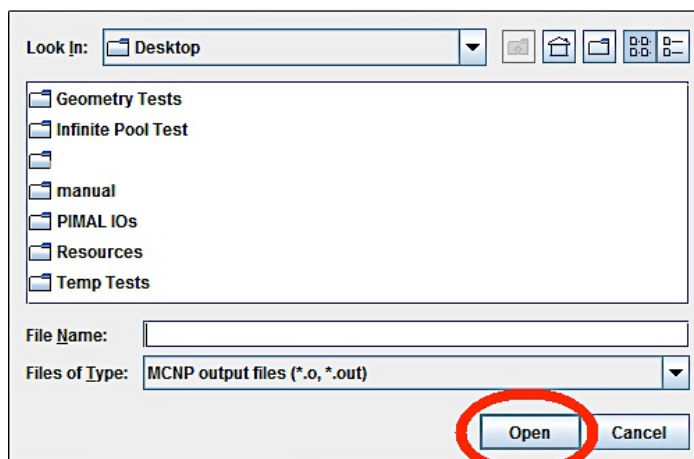


Figure 46 Output Selection Window

The organ dose chart (see Figure 45) appears in a popup window. The tally computed by MCNP® is converted to Gy/(source particle) using the energy deposition tally (F6) for each cell

and the known organ masses. Relative error for the dose is shown in the column to the right. If photonuclear effects are turned on (MODE n p), the neutron dose will be displayed, along with total dose from both particle types.

The columns may be resized. Place the cursor over the dividing lines until the mouse changes into a horizontal line. Click and drag in the desired directions to resize.

The chart may also be exported as an ASCII .dat file, which may be opened in a text editor. To save the organ doses as an ASCII file, click on the *Export to ASCII* button (see Figure 45), and save the file.

7 TUTORIALS

These tutorials cover the basics of using PIMAL to accomplish realistic modeling needs. The tutorials also cover editing the MCNP® files outside of PIMAL to go beyond the capabilities of PIMAL.

7.1 Female Extension Pose (AP Source) - Beginner User



Figure 47 Female Phantom in Extension Pose

The first tutorial describes a female phantom articulated in an extended reaching pose that is exposed to an AP source of cobalt-60. This first tutorial details the basic methodology for using PIMAL to calculate organ dose from a source defined within PIMAL.

Step 1. By default, PIMAL opens the Mathematical FEMALE Phantom; if the Mathematical FEMALE phantom is not selected, click on *Phantom > Mathematical Phantoms > Mathematical FEMALE Phantom model* in the toolbar.

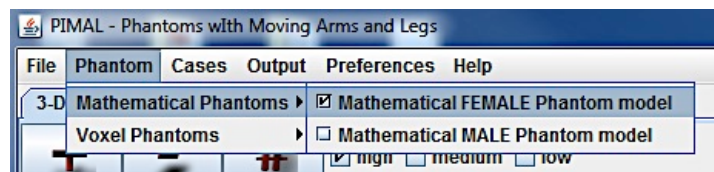


Figure 48 Open Mathematical Female Phantom

Step 2. In the phantom parameters section, select the *Sliders* tab.

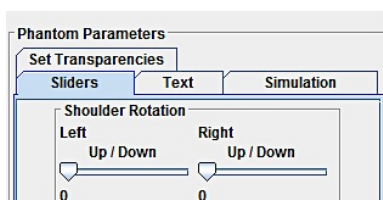


Figure 49 Phantom Parameters Window - Female Extension

Step 3. Appendage rotations set using sliders are shown. The phantom should appear as shown at the beginning of the tutorial.

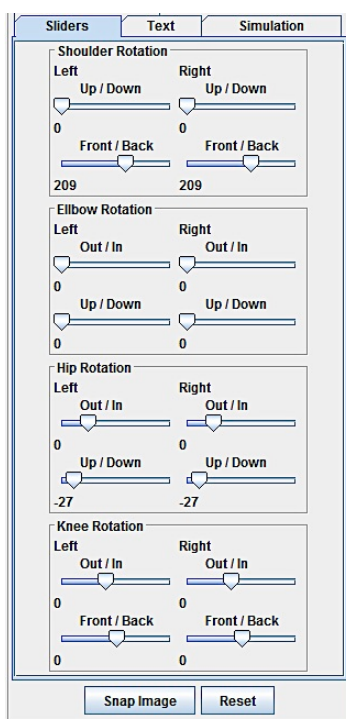


Figure 50 Phantom Sliders Tab - Female Extension

Phantom Parameters

Set Transparencies Sliders Text **Simulation**

Energy (MeV)
 Co-60 ▼ E 10.0

Position
 Antero-Posterior (AP) ▼ x 50
 y 0
 z 100

Number of Particles 1.0E5

Generate MCNP Input

Figure 51 Phantom Simulation Tab - Female Extension

Step 4. Set the *Energy (MeV)* dropdown menu selection to *Co-60*.

Step 5. Set the *Source Geometry* dropdown menu selection to *Antero-Posterior (AP)*.

Step 6. The last entry is for the *Number of Particles* (NPS) to be run by MCNP®. For this tutorial, set the NPS to a small value: 1.0E5.

Step 7. Select *Generate MCNP Input*.

Step 8. To verify the source geometry, display the source points of this setup. Ignore the MCNP® input popup menu and click on *Preferences > Set Source Display Number* in the toolbar. Enter in 6000 display points and select *Save*.

Number of source points: 6000

Save Cancel

Figure 52 Set Source Display Number - Female Extension

Step 9. On the popup menu generated in step 8, deselect *Set All Organs Transparent* and select the *Display Source Points* button.

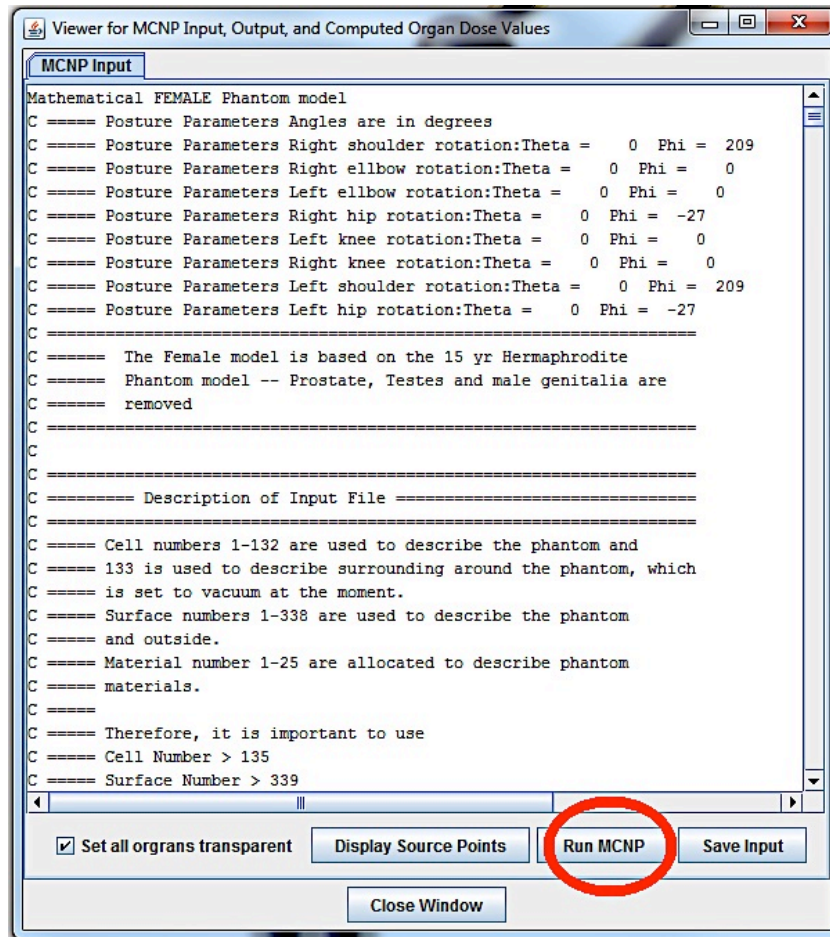


Figure 53 MCNP® Input - Female Extension

Step 10. The phantom should now be shown in the main window. Return to the *Viewer for MCNP* window, select the *MCNP Input*, and select *Run MCNP*.

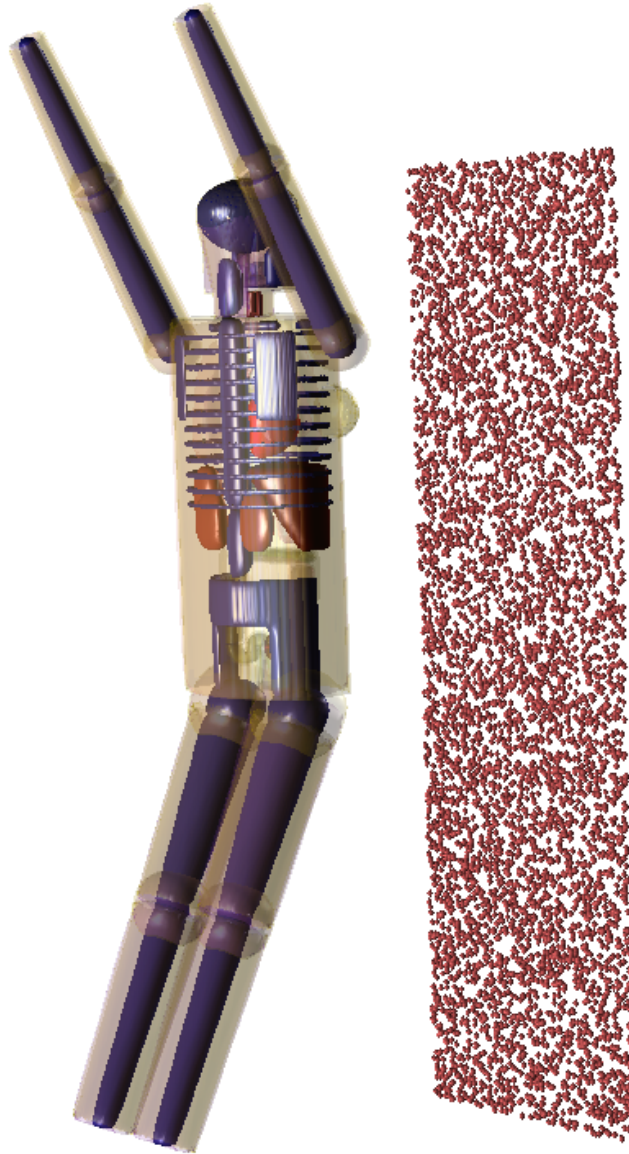


Figure 54 Female Extension Phantom with Source Point Display (*Posterior View*)

Step 11. Be certain that MCNP® runs in another tab of the window. MCNP® requires a short amount of time to run the 1.0E5 particles. If fatal errors are encountered at this point, or during source point display, ensure that the input in the first tab was not altered.

```

250      ty 1.18 0 7.86 1.18 1.76 1.18
warning. singular torus. it can fail in plotting or tracking.

warning. non-orthogonality of surface transformation      3 > 2.e-6
warning. non-orthogonality of surface transformation      4 > 2.e-6
m9      1001      -0.105
warning. material          9 is not used in the problem.
m22     1001      -0.106
warning. material         22 is not used in the problem.

comment.          50 surfaces were deleted for being the same as others.
warning.          3 materials had unnormalized fractions. print table 40.
warning. surface      3 is not used for anything.
warning. surface     37 is not used for anything.
warning. surface     38 is not used for anything.
warning. surface     70 is not used for anything.
warning. surface    254 is not used for anything.
comment. using random number generator 1, initial seed = 19073486328125
imcn  is done

          ctm =          0.00  nrn =          0
dump   1 on file runtpe  nps =          0  coll =          0
xact  is done

cp0 =  0.05

          ctm =          0.01  nrn =        182649
dump   2 on file runtpe  nps =       10000  coll =         8304

          ctm =          0.02  nrn =        369066
dump   3 on file runtpe  nps =       20000  coll =        16871

```

Close Window

Figure 55 Female Extension MCNP® Run

Step 12. When the MCNP® is finished, the organ dose table appears. Data could be written and entered into another file or exported as an ASCII .dat file. Select the *Close Window* button to complete this tutorial.

MCNP Input

MCNP Screen Output

MCNP Full Output

Computed Organ Dose Values

Math_Female_0.o

Absorbed Dose (Gy/Source Particle) for NPS=1.0E5

Organs	Photon Dose Tally: 216	Relative Error (1 sigma) Tally: 216
ovaries	4.2330E-16	0.1050
bone marrow	5.2450E-16	0.0119
colon	5.4392E-16	0.0258
lungs	5.6271E-16	0.0204
stomach	6.6493E-16	0.0342
urinary bladder	6.1123E-16	0.0505
breast	6.2067E-16	0.0272
liver	5.9311E-16	0.0235
esophagus	5.0903E-16	0.0476
thyroid	7.2049E-16	0.0816
skin	6.4582E-16	0.0152
bone surface	4.7641E-16	0.0116
adrenals	5.4029E-16	0.0996
brain	5.1245E-16	0.0306
Extrathoracic airways	5.8048E-16	0.0712
small intestine	5.6149E-16	0.0255
kidneys	4.3299E-16	0.0352
muscle	5.1650E-16	0.0068
pancreas	5.6594E-16	0.0416
spleen	5.2665E-16	0.0492
thymus	6.5309E-16	0.0636
uterus	6.2048E-16	0.0827
eyes	6.0562E-16	0.1069

Export to ASCII

Close

Close Window

Figure 56 Female Extension Phantom Computed Organ Dose Values

7.2 Male Voxel Phantom (AmBe Point Source) - Intermediate User



Figure 57 Male Voxel Phantom

This tutorial covers the modeling of the male anatomy, represented by the built-in ICRP Voxel Phantom, exposed to an isotropic AmBe neutron point source. The Voxel Phantom is a closer representation of the human body than the Mathematical Model, but it is not possible to move the appendages. The MCNP® input file will run outside of PIMAL using MCNP6®, and the output file will be viewed within PIMAL.

Step 1. Click on *Phantom > Voxel Phantoms > ICRP's MALE Voxel Phantom Model* in the PIMAL toolbar.

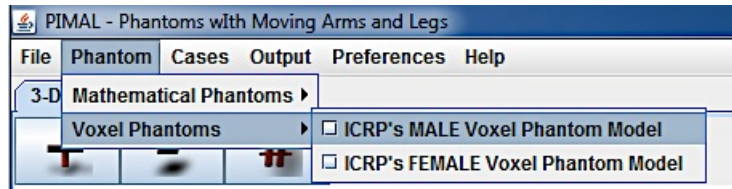


Figure 58 Open ICRP's MALE Voxel Phantom Model

Step 2. The *Simulation* tab should be open by default; if not, select it.

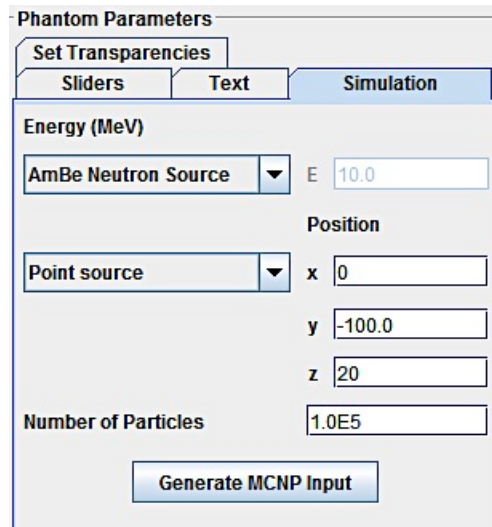


Figure 59 Phantom Simulation Tab - Male Voxel

Step 3. In the *Energy (MeV)* dropdown menu, select *AmBe Neutron Source*.

Step 4. In the third dropdown menu, select *Point source*. For this setup, the point source is set to be 1 meter from the front of the body. Enter the positioning values as seen in Figure 59.

Step 5. The last entry is for the *Number of Particles* to be run by MCNP®. For this tutorial, set the NPS to a relatively small value: 1.0E5

Step 6. Select the *Generate MCNP Input* button.

Step 7. For this tutorial, the generated MCNP® input file is taken outside of PIMAL to run in the MCNP® command prompt. Select the *Save Input* button.

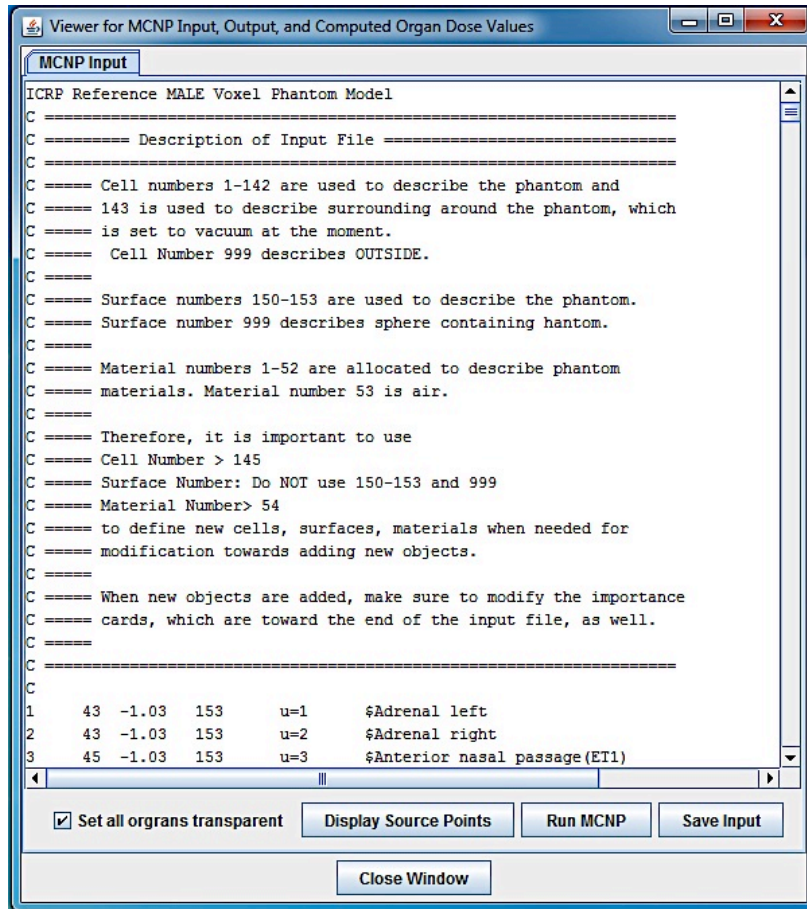


Figure 60 MCNP® Input - Male Voxel

Step 8. Name the file and save it in a convenient location, then select the Save button.

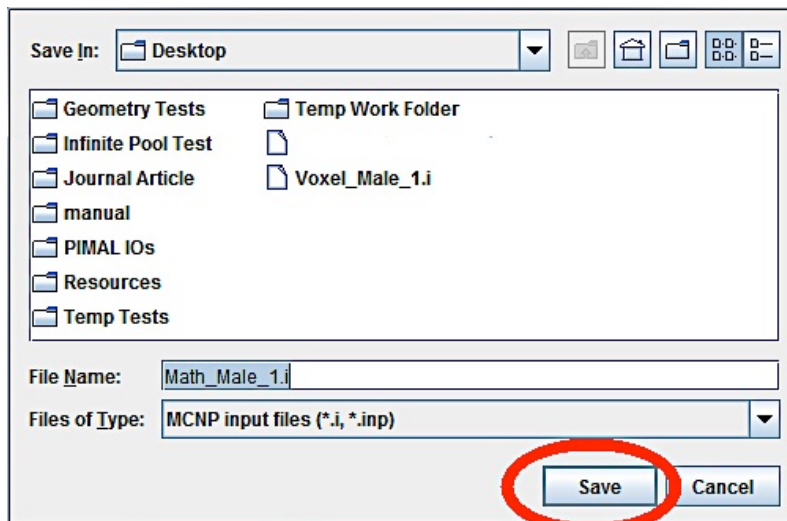


Figure 61 Save MCNP® Input File - Male Voxel

Step 9. Open the MCNP® command prompt. Change the working directory to the directory to which the file was saved in the previous step. As seen in Section 6.2, “Running MCNP® through the Command Prompt,” be sure to use the correct syntax to run the input file. At 1.0E5 particles, the run should be quick once initialized.

Note: Voxel Phantom input files must be run in MCNP6®/MCNP611® or MCNPX® and not in MCNP5®.

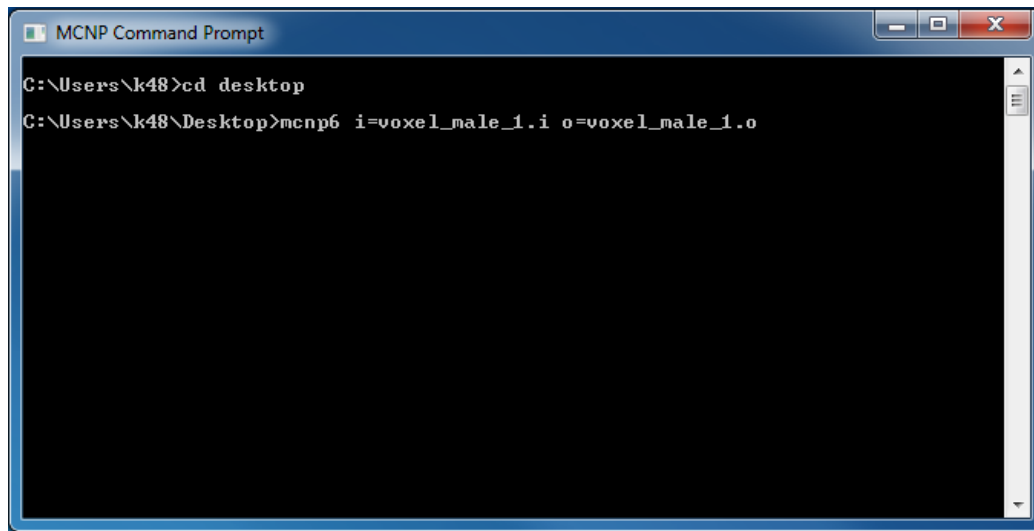


Figure 62 MCNP® Command Prompt - Male Voxel

Step 10. To view the results of the run, open the output file through PIMAL. In the PIMAL toolbar, click on *Output > View Organ Dose*. Select the output file and select the *Open* button.

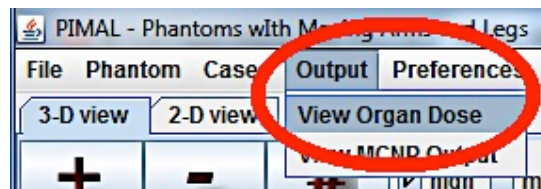


Figure 63 PIMAL View Organ Dose - Male Voxel

Step 11. The absorbed doses for 28 organs are shown. The total dose is the sum of neutron dose and photon dose. The MCNP® output file can also be viewed through PIMAL; in the PIMAL toolbar click on *Output > View MCNP Output*.

voxel_male_2.o

Absorbed Dose (Gy/Source Particle) for NPS=1.0E5

Organs	Neutron Dose Tally: 116	Relative Error (1 sigma) Tally: 116	Photon Dose Tally: 126	Relative Error (1 sigma) Tally: 126	Total Dose Tally: 106	Relative Error (1 sigma) Tally: 106
Colon Wall	7.8613E-17	0.1639	9.8986E-18	0.2261	8.8511E-17	0.1500
Lung	4.9283E-17	0.1794	5.9391E-18	0.2668	5.5222E-17	0.1677
Stomach wall	5.5265E-17	0.3007	8.0734E-18	0.3510	6.3338E-17	0.2666
Breast	1.7370E-16	0.4092	4.5329E-18	0.7655	1.7824E-16	0.3992
Red Bone Marrow	8.9150E-17	0.0562	4.8253E-18	0.1445	9.3975E-17	0.0545
Testes	1.3581E-16	0.5015	1.7269E-17	0.8494	1.5308E-16	0.4558
Urinary Bladder ...	1.2513E-16	0.2606	1.6341E-17	0.3563	1.4147E-16	0.2343
Oesophagus Wall	2.3226E-17	0.5860	1.2196E-18	0.7133	2.4446E-17	0.5580
Liver	5.8482E-17	0.1989	1.0240E-17	0.2730	6.8722E-17	0.1754
Thyroid	1.3444E-16	0.5257	0.0000E00	0.0000	1.3444E-16	0.5257
Bone Surface	4.0858E-17	0.0519	4.4989E-18	0.1526	4.5356E-17	0.0504
Brain	3.3374E-17	0.2816	3.9042E-19	1.0000	3.3764E-17	0.2786
Salivary Glands	5.7121E-17	0.4164	0.0000E00	0.0000	5.7121E-17	0.4164
Skin	1.1789E-16	0.0319	3.5610E-18	0.0931	1.2145E-16	0.0314
Adrenals	3.0369E-17	0.8665	4.2536E-18	1.0000	3.4623E-17	0.7700
ET region	2.2401E-17	0.4276	0.0000E00	0.0000	2.2401E-17	0.4276
Gall Bladder Wall	3.0480E-17	0.5004	5.8652E-18	0.6513	3.6346E-17	0.4326
Heart Wall	5.1110E-17	0.3209	3.3460E-18	0.3666	5.4456E-17	0.3028
Kidneys	3.5978E-17	0.5075	4.1132E-18	0.4985	4.0091E-17	0.4583
Lymph Nodes	9.8479E-17	0.1338	7.3606E-18	0.2251	1.0584E-16	0.1262
Muscle	1.0094E-16	0.0348	6.4925E-18	0.0955	1.0743E-16	0.0342
Oral Mucosa	9.3696E-18	0.6828	0.0000E00	0.0000	9.3696E-18	0.6828
Pancreas	7.8330E-17	0.3737	9.5702E-18	0.4640	8.7900E-17	0.3369
Prostate	1.0431E-16	0.5129	2.6326E-18	1.0000	1.0694E-16	0.5009
Small Intestine	9.1625E-17	0.1235	1.2802E-17	0.1986	1.0443E-16	0.1146
Spleen	2.3502E-17	0.6961	8.5651E-18	0.6811	3.2067E-17	0.5438
Thymus	7.2591E-17	0.5816	0.0000E00	0.0000	7.2591E-17	0.5816
Eye lenses	0.0000E00	0.0000	0.0000E00	0.0000	0.0000E00	0.0000

Export to ASCII Close

Figure 64 Male Voxel Phantom MCNP® Output

Step 12. Select the *Close* button to conclude this tutorial.

7.3 Water Submersion - Advanced User

A practical example would be to use PIMAL to determine the dose to human organs from a surrounding body of contaminated water. This tutorial covers complex issues encountered when PIMAL is applied to realistic situations - the introduction of new materials and source geometries to the model. In this case, a male mathematical phantom is placed into a large body of contaminated water, where the contaminant releases photons with energy 0.5 MeV.

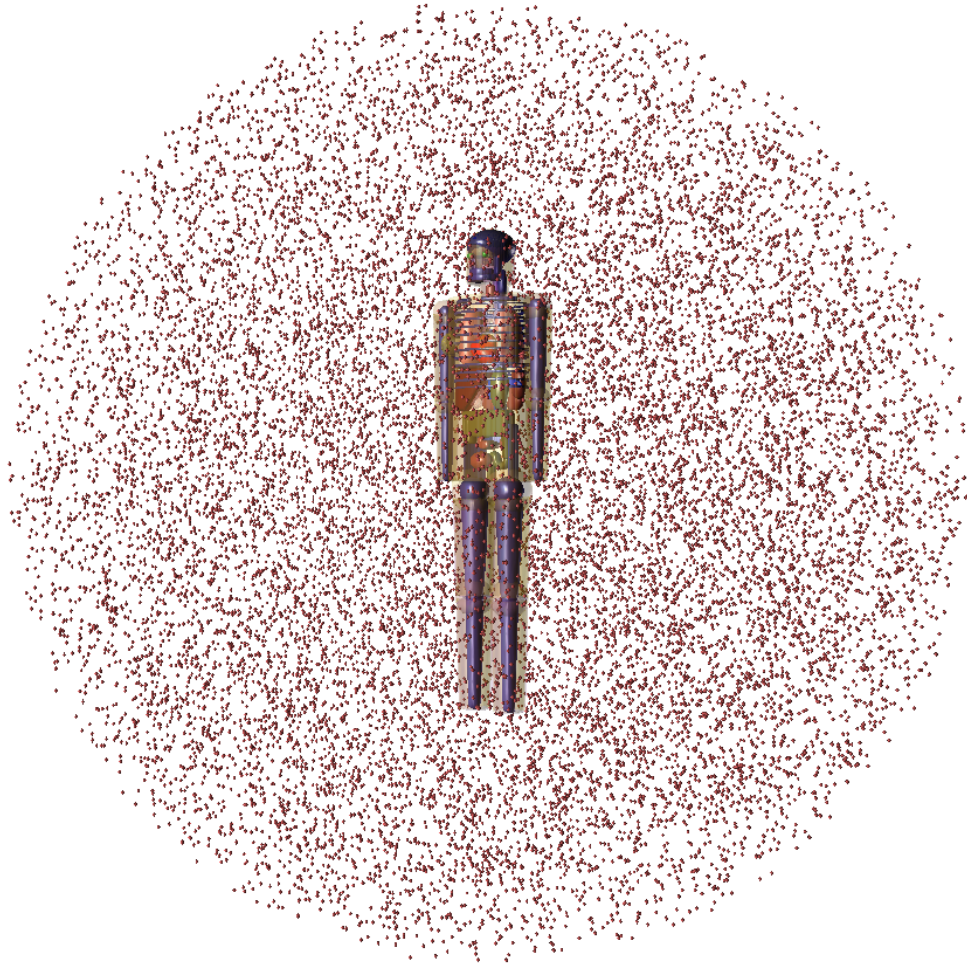


Figure 65 Water Submersion with Male Mathematical Phantom

Step 1. Click on *Phantom > Mathematical Phantoms > Mathematical MALE Phantom model* in the PIMAL toolbar.

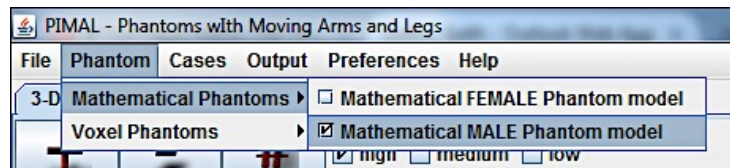


Figure 66 Open Mathematical Male Phantom

Step 2. Select the *Simulation* tab in the *Phantom Parameters* menu. Set the Number of Particles to 1.0E5 in this example.

The screenshot shows the 'Phantom Parameters' dialog box with the 'Simulation' tab selected. The 'Energy (MeV)' section has a dropdown menu set to 'Co-60' and a text box for 'E' set to '10.0'. The 'Position' section has a dropdown menu set to 'Antero-Posterior (AP)' and text boxes for 'x' (0), 'y' (-100.0), and 'z' (20). The 'Number of Particles' text box is set to '1.0E5'. A 'Generate MCNP Input' button is at the bottom.

Figure 67 Phantom Simulation Tab - Water Submersion

Step 3. No other settings on the Simulation menu are needed; the source definition changes will be made outside of PIMAL. Select the *Generate MCNP Input* button.

Step 4. The MCNP® input will be edited in PIMAL. The first priority is to add a material card for water. As shown, it is important to use material numbers 26 or greater.

The screenshot shows the 'Viewer for MCNP Input, Output, and Computed Organ Dose Values' window. The 'MCNP Input' tab is active, displaying the generated input file. The text includes comments about the Mathematical Male Phantom Model, posture parameters, and material definitions. At the bottom, there are buttons for 'Set all organs transparent', 'Display Source Points', 'Run MCNP', 'Save Input', and 'Close Window'.

Figure 68 MCNP® Input 1 - Water Submersion

Step 5. Navigate to the location in the MCNP® input file as shown, and enter the material for water (in this case, material M26) as shown.

```

MCNP Input
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
C
M25      1001      -0.116
         6000      -0.519
         8016      -0.365

C =====
C ===== WATER -- Density = 1.00 g/cc =====
C =====
C
C
M26      1001      -0.1119
         8016      -0.8881
mt26     lwtr.01t

C
C
C
C =====
C TALLY DEFINITION SECTION
C =====
C
C
C ENDORGAN

```

Figure 69 MCNP® Input 2 - Water Submersion

Step 6. A spherical vacuum around the phantom already exists in the input file generated by PIMAL (cell 135 for MALE). Go to the line for cell 133 and change from vacuum 0 to Water with a density of 1.00 g/cm³: 26 -1.00. Note that cell 135 is defined as inside surface 294.

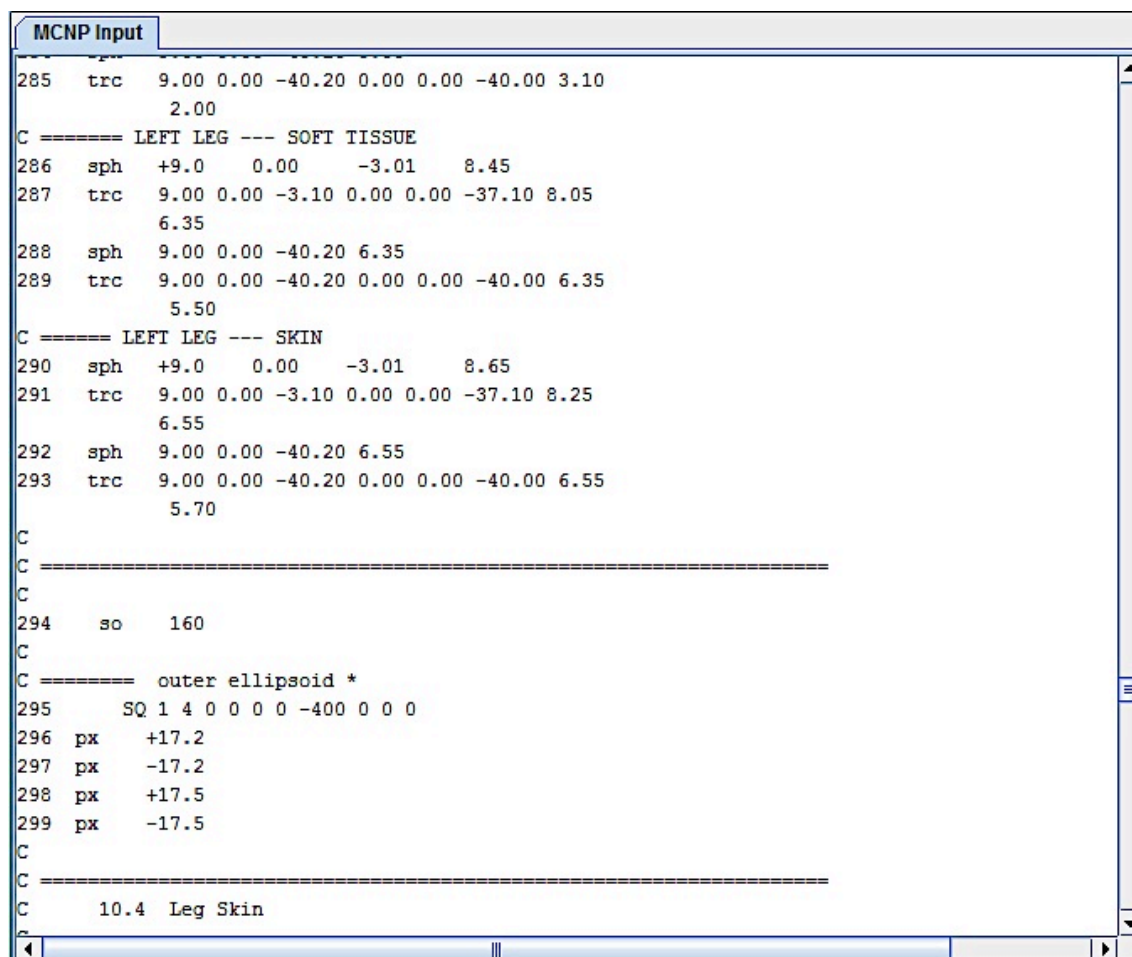
[illegible]

Figure 70 MCNP® Input 3 - Water Submersion

Step 7. When an infinite body of water is defined for submersion testing, the spherical water volume has to be large enough to contain all source points that could affect dose calculations; at the same time, an arbitrarily large sphere of source points may include a majority of source points that have no chance of reaching the phantom.

For this tutorial, make the sphere at least 6 mean free paths away from the body at all points. The height of the body from the origin is approximately 100 cm (in positive z direction) and the mean free path of a 0.5 MeV photon in water is approximately 10 cm. Therefore, the radius of the sphere gets set to 160 cm.

Navigate to surface 294, and change it to 160 cm.



```

MCNP Input
285   trc   9.00 0.00 -40.20 0.00 0.00 -40.00 3.10
      2.00
C ===== LEFT LEG --- SOFT TISSUE
286   sph   +9.0   0.00   -3.01   8.45
287   trc   9.00 0.00 -3.10 0.00 0.00 -37.10 8.05
      6.35
288   sph   9.00 0.00 -40.20 6.35
289   trc   9.00 0.00 -40.20 0.00 0.00 -40.00 6.35
      5.50
C ===== LEFT LEG --- SKIN
290   sph   +9.0   0.00   -3.01   8.65
291   trc   9.00 0.00 -3.10 0.00 0.00 -37.10 8.25
      6.55
292   sph   9.00 0.00 -40.20 6.55
293   trc   9.00 0.00 -40.20 0.00 0.00 -40.00 6.55
      5.70
C
C =====
C
294   so    160
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

```

Figure 71 MCNP® Input 4 - Water Submersion

Step 8. Finally, the photon source has to be defined. In the source definition, a sphere slightly larger than cell 135 must be defined as source volume. Using the cell rejection technique, only source particles that start within cell 135 are accepted.

Several changes have to be made in the SDEF section of the input file:

- ERG defines the source energy in MeV, e.g., 0.5 MeV.
- CEL defines which cell is used to sample, 135 here.
- Add an SI1 card that defines the radius of the source, here 161 cm: SI1 0 161.
- Add an SP1 card that defines radial distribution to equally sample the volume of the sphere: SP1 -21 2.

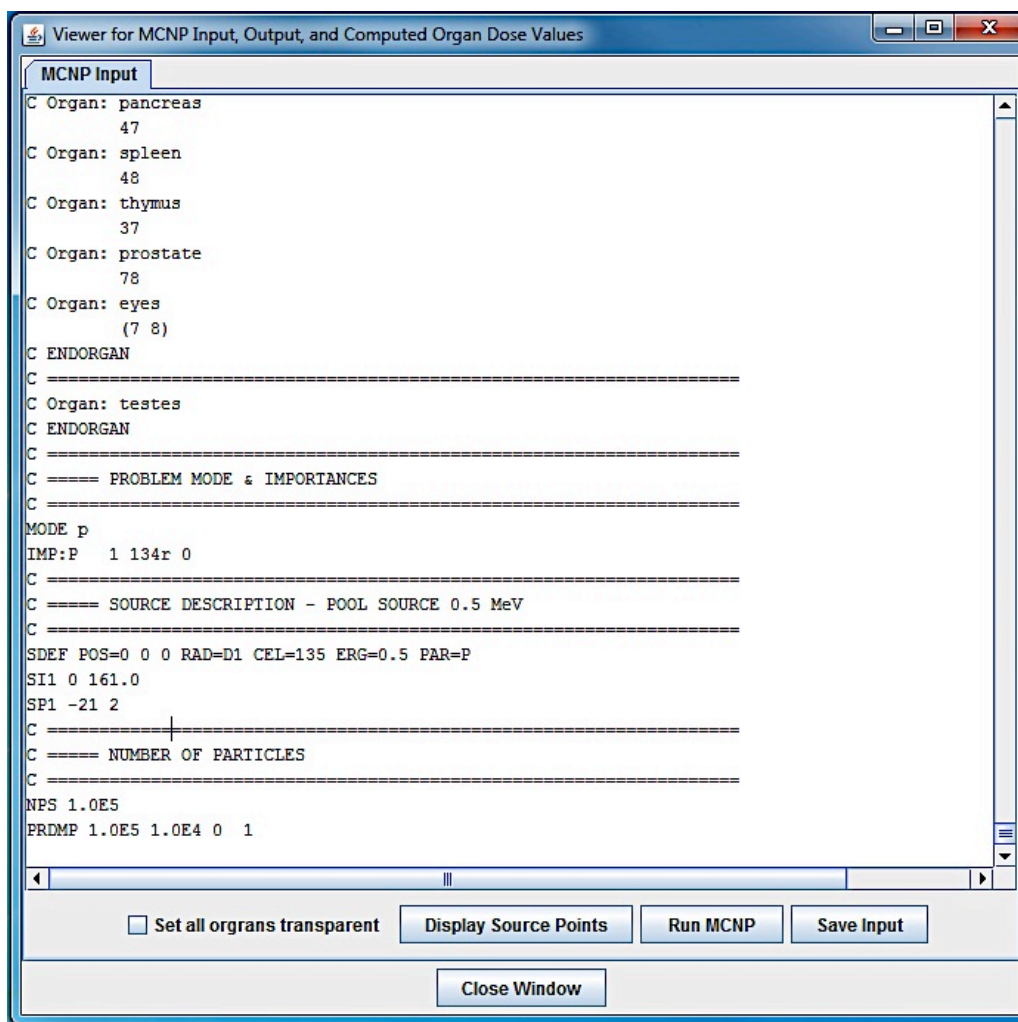


Figure 72 MCNP® Input 5 - Water Submersion

Step 9. Click on *Display Source Points* to verify the source.

Step 10. After editing, click on *Save Input* to save the input file.

Step 11. Open up the command prompt and go to the directory containing the input file. Start the MCNP® simulation. See Section 6.2, “Running MCNP® through the Command Prompt,” for details.

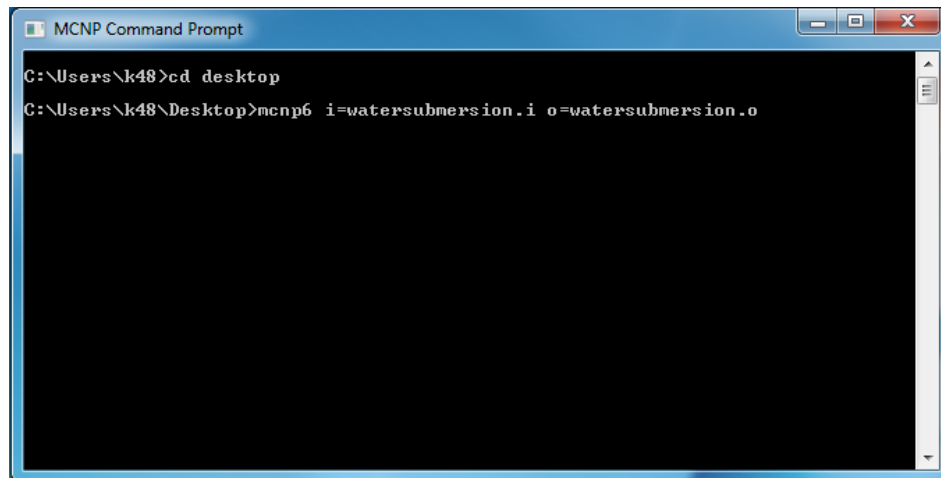


Figure 73 MCNP® Command Prompt - Water Submersion

Step 12. Wait for the MCNP® run to complete.

Step 13. To view the parsed results of the run, open the output file through PIMAL. In PIMAL, click on *Output > View Organ Dose* from the toolbar. Select the output file and select *Open*.

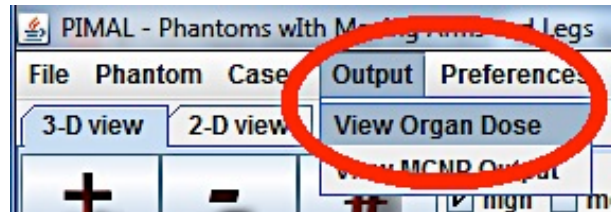


Figure 74 PIMAL View Organ Dose - Water Submersion

Step 14. The data is now accessible in a user-friendly manner. The original output file itself can also be viewed through PIMAL in *Output > View MCNP Output*.

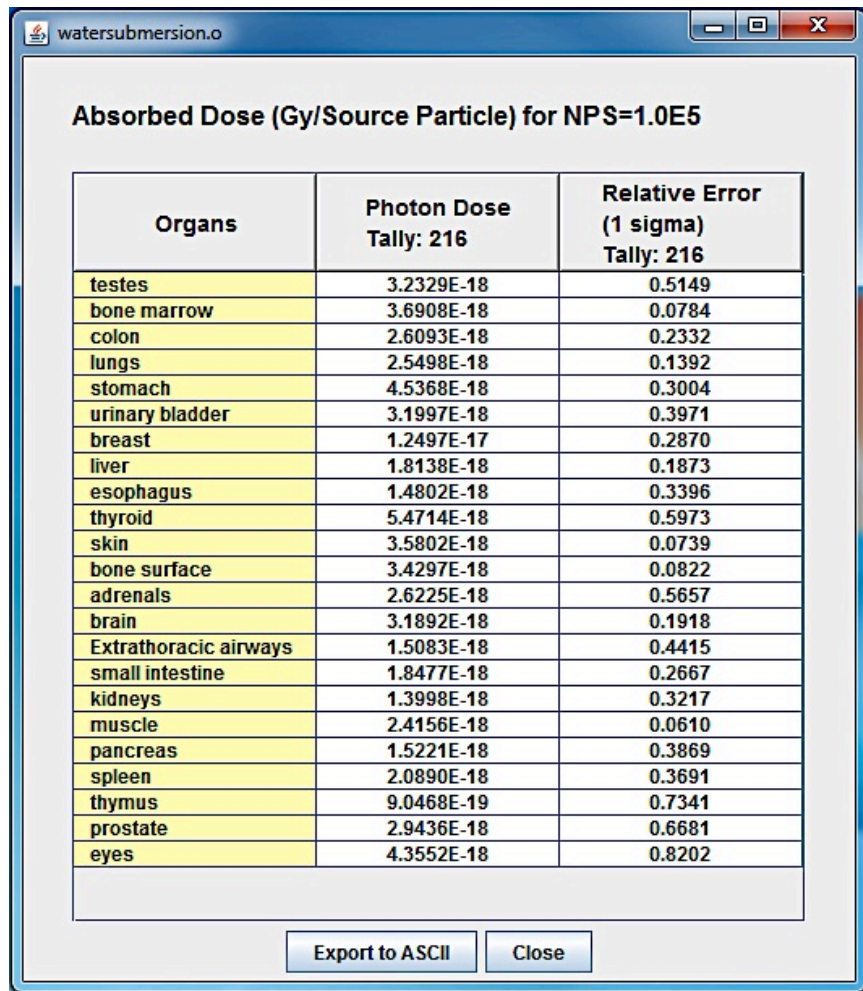


Figure 75 Water Submersion MCNP® Output

Step 15. Select *Close* to conclude this tutorial.

8 REFERENCES

1. Xu, X.G., *An exponential growth of computational phantom research in radiation protection, imaging, and radiotherapy: a review of the fifty-year history*. Physics in medicine and biology, 2014. **59**(18): p. R233.
2. Akkurt, H. and K.F. Eckerman, *Development of PIMAL: Mathematical Phantom with Moving Arms and Legs*, ORNL/TM-2007/14. 2007, Oak Ridge National Laboratory: Oak Ridge.
3. Akkurt, H., et al., *PIMAL: Phantom with Moving Arms and Legs*. Transactions of the American Nuclear Society, 2007. **96**: p. 396-397.
4. International Commission on Radiological Protection, *Conversion Coefficients for use in Radiological Protection against External Radiation. ICRP Publication 74*. Annals of the ICRP, 1996. **26**(3-4): p. .
5. Pelowitz, D.B., *MCNP6 User's Manual Version 1.0*. 2013.
6. Akkurt, H., et al., *A GUI for Computational Phantom with Moving Arms and Legs*. Transactions of the American Nuclear Society, 2007. **96**: p. 640-641.
7. International Commission on Radiological Protection, *ICRP Publication 110: Adult Reference Computational Phantoms*. Annals of the ICRP, 2009. **39**.
8. International Commission on Radiological Protection, *Nuclear Decay Data for Dosimetric Calculations. ICRP Publication 107*. Annals of the ICRP, 2009. **38**(3): p. .
9. Pelowitz, D.B., A.J. Fallgren, and G.E. McMath, *MCNP6 User's Manual, Code Version 6.1.1 beta*. 2014, Los Alamos National Laboratory: Los Alamos.

APPENDIX A DETAILED DESCRIPTION OF PHANTOM INPUT FILES

This appendix contains a description of the cells and the surfaces that make up the cells for both the male and female phantom in PIMAL. A description of the material definitions and tally descriptions are also included.

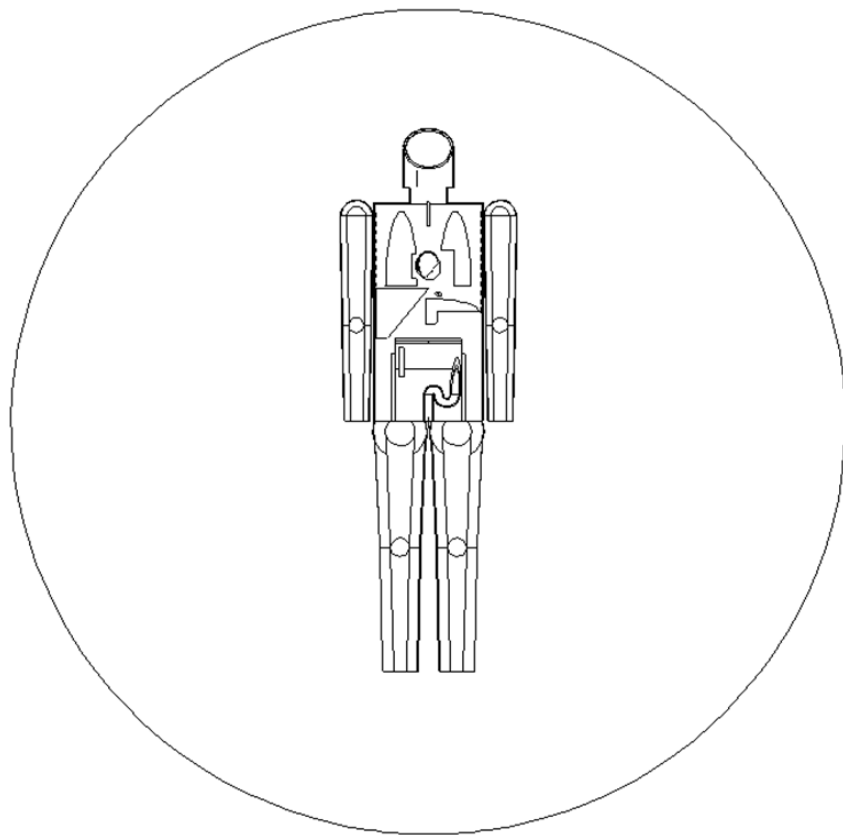


Figure A-1 Male PIMAL View in the Visual Editor (VisEd) software {Schwarz, 2011 #30}

Male Phantom in PIMAL

Note that cell 135 is vacuum.

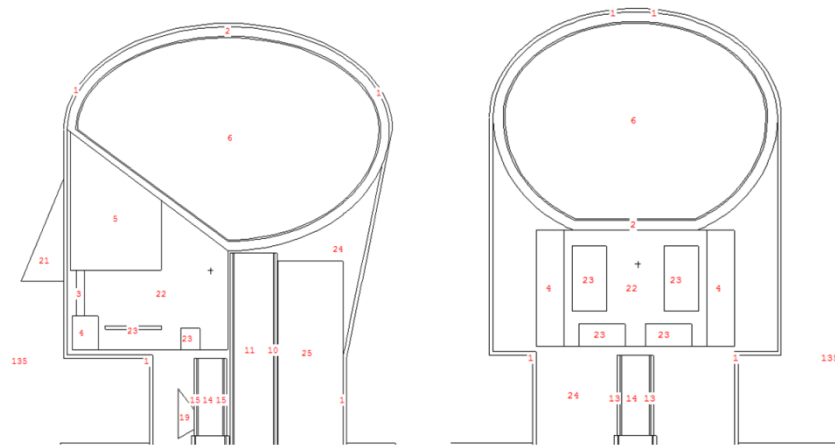


Figure A-2 Male Phantom Head and Neck Area

Table A-1 Male Phantom Head and Neck Area Cell Descriptions

Cell	Organ/Tissue/Body Part	Further descriptions (surfaces)
1	Skin of Head/Neck	
2	Cranium	
3	Teeth	Region between two ellipsoid halves (21&22)
4	Mandible	
5	Nasal Cavity	
6	Brain	Inside ellipsoid bisected by planes
7,8	Eyes	Inside ellipsoids (31,32) *not depicted*
9	Total Sinuses	*not depicted*
10-18	Residual/Mucosa Walls	Gastrointestinal walls - pharynx, larynx, trachea
19	Thyroid	
20,21	Nose	Nose contents and nose wall
22	Oral Cavity	Soft tissue behind mouth and teeth
23	Salivary Glands	
24	Neck muscle	

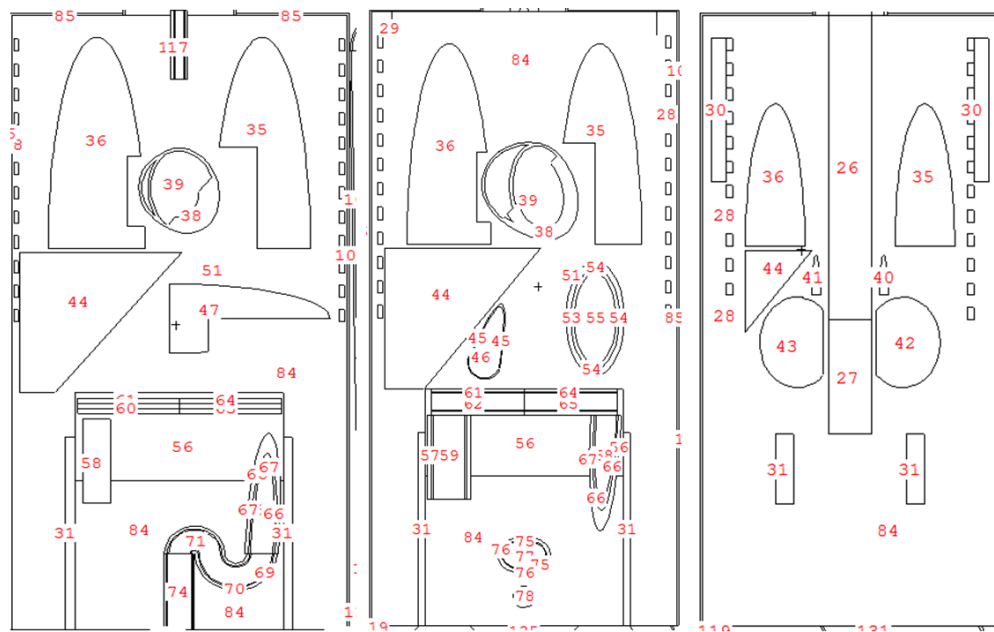


Figure A-3 Male Phantom Chest of Body

Table A-2 Male Phantom Chest of Body Cell Descriptions

Cell	Organ/Tissue/Body Part	Further descriptions (surfaces)
25,26,27	Vertebra	Cervical *not depicted* and thoracic and lumbar
28	Ribs	
29	Clavicles	
30	Scapulae	
31	Pelvis Bone	
32-34	Main Bronchi	Residual/mucosa wall and contents *not depicted*
35,36	Lungs	Left and right lung
37	Thymus	Inside ellipsoid (150)
38,39	Heart	
40,41	Adrenals	Ellipsoids (163,164) bisected by plane
42,43	Kidneys	Ellipsoids (166,167) bisected by planes
44	Liver	Ellipsoid (173) bisected by planes
45,46	Gall Bladder	
47	Pancreas	
48	Spleen	Ellipsoid (187) *not depicted*
49-52	Esophagus	*not depicted*
53-55	Stomach	Ellipsoids (195,196,197)
56	Small Intestine	
57-68	Left & Right Colon	
69-71	Sigmoid Colon	
72-74	Rectum	

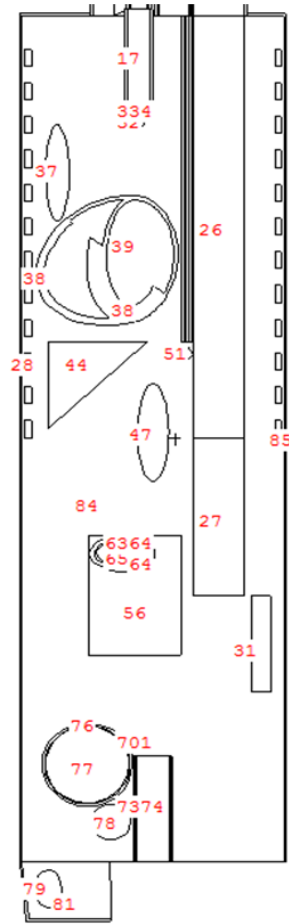


Figure A-4 Male Phantom Chest of Body - Side View

Table A-3 Male Phantom Chest of Body - Side View Cell Descriptions

Cell	Organ/Tissue/Body Part	Further descriptions (surfaces)
73,74	Rectum	
75-77	Urinary Bladder	
78	Prostate	Sphere (227)
79,80	Testes	Ellipsoids (231,232)
81	Male Genitalia	
82,83	Male Breasts	*not depicted*
84	Muscle in Trunk	Defined outside all defined organs, inside body
85	Skin of Trunk	Sphere (227)
86	Skin of Male Genitalia	*not depicted*

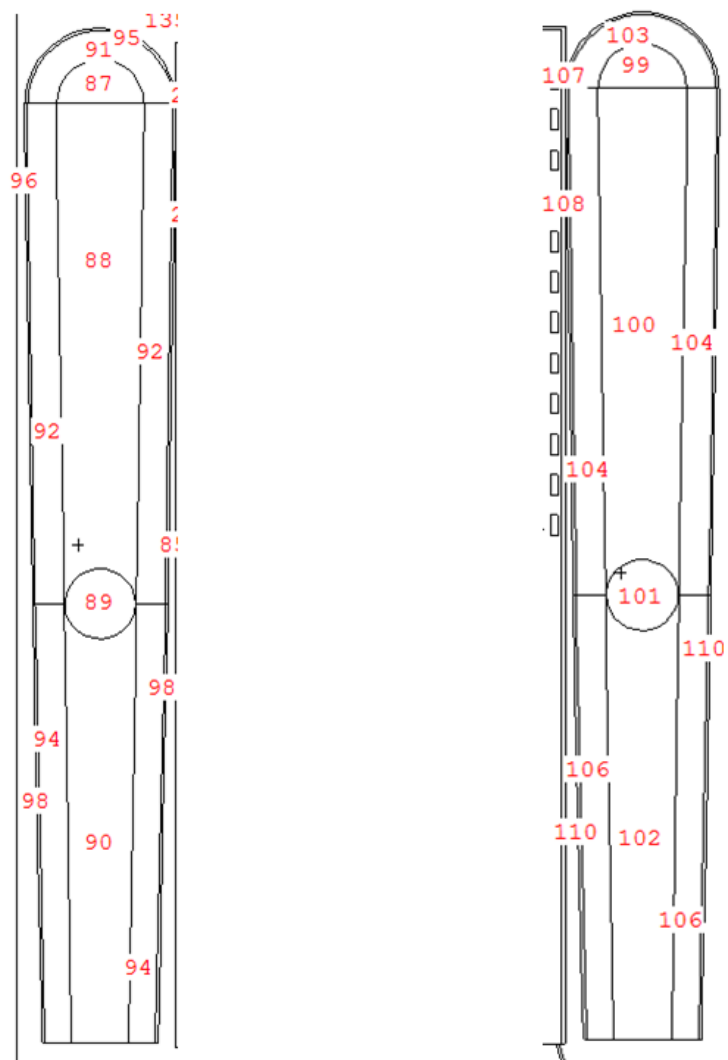


Figure A-5 Male Phantom Arms

Table A-4 Male Phantom Arm Cell Descriptions

Cell	Organ/Tissue/Body Part	Further descriptions (surfaces)
87-90	Right Arm Bone	
91-94	Right Arm Soft Tissue	93 - Very small soft tissue area *not depicted*
95-98	Right Arm Skin	
99-102	Left Arm Bone	
103-106	Left Arm Soft Tissue	105 - Very small soft tissue area *not depicted*
107-110	Left Arm Skin	

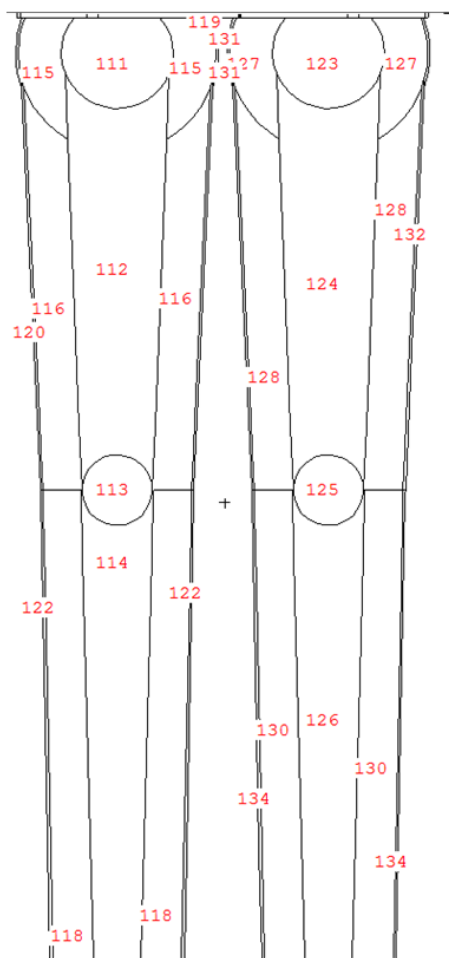


Figure A-6 Male Phantom Legs and Surroundings

Table A-5 Male Phantom Legs and Surroundings Cell Descriptions

Cell	Organ/Tissue/Body Part	Further descriptions (surfaces)
111-114	Right Leg Bone	
115-118	Right Leg Tissue	117 - Very small tissue area *not depicted*
119-122	Right Leg Skin	
123-126	Left Leg Bone	
127-130	Left Leg Tissue	129 - Very small tissue area *not depicted*
131-134	Left Leg Skin	
135	Vacuum Around Phantom	Sphere completely encompassing phantom
136	Particle Graveyard	Outside of 135

Female phantom in PIMAL

Note that cell 133 is vacuum.

Note that geometries are similar between the male and female phantoms, except for what is noted below.

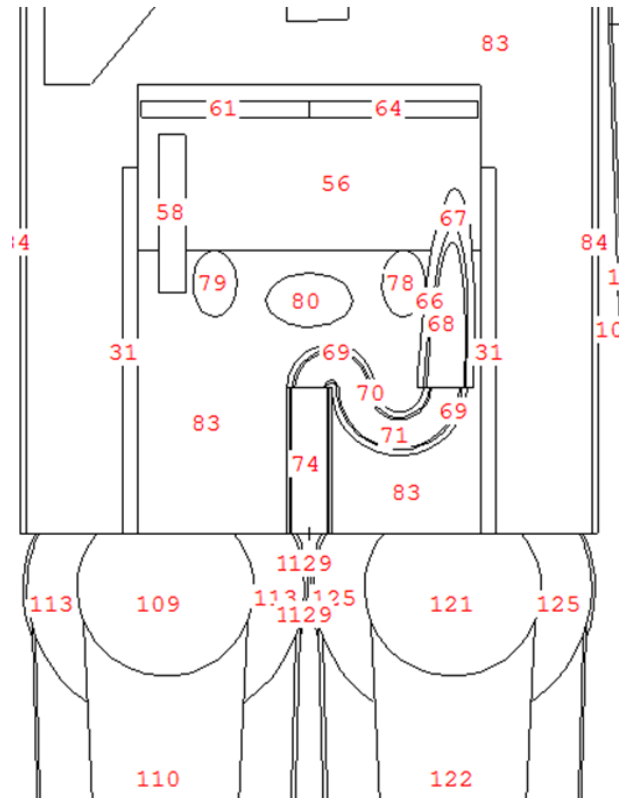


Figure A-7 Female Phantom Lower Chest

Table A-6 Female Phantom Lower Chest Cell Descriptions

Cell	Organ/Tissue/Body Part	Further descriptions (surfaces)
78	Left Ovary	Inside an ellipsoid (272)
79	Right Ovary	Inside an ellipsoid (273)
80	Uterus	Inside an ellipsoid (274) bisected by plane (275)

Material Definitions

```

C =====
C
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 -0.00002
        15031 -0.05095
        16000 -0.00173
        17000 -0.00143
        19000 -0.00153
        20000 -0.10190
        26000 -0.00008
        30000 -0.00005
mt2      lwtr.01t
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  -0.240690
        7014  -0.027735

```

Figure A-8 Material Cards

Materials are designated by the M# cards. New defined materials must have numbers >25, PIMAL itself uses materials 1-25.

Tally Descriptions

F6 tallies are utilized by PIMAL to find the dose to each of the organs:

- F116 tally collects the neutron dose contribution.
- F216 tally collects the photon dose contribution.
- F316 tally collects both the neutron and photon dose contribution.

APPENDIX B LIMITATIONS IN USING PIMAL

Physical limitations on appendage rotations are as follows:

- Left/Right shoulder rotation: 0-180; 0-358
- Left/Right elbow rotation: 0-180; 0-358
- Left/Right hip rotation: -25-79; -39-79
- Left/Right knee rotation: -60-90; -90-90

APPENDIX C VALIDATION AND VERIFICATION

Benchmark computations for PIMAL are fully documented in Section 3 of the following document:

H. Akkurt and K. Eckerman. *Development of PIMAL: Mathematical Phantom with Moving Arms and Legs*, ORNL/TM-2007/14, Oak Ridge National Laboratory (May 2007). Available at: https://crpk.ornl.gov/documents/ORNL_TM-2007_14.pdf.

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11. ABSTRACT (200 words or less)

Computational phantoms with articulated arms and legs have been developed to enable radiation dose estimation for male and female receptors in different postures. Using a user-friendly graphical user interface (GUI), the PIMAL (**Phantom w**lth **Moving Arms and Legs**) software can be employed to adjust the posture of a phantom, generate a corresponding input file for the Monte Carlo N-Particle (MCNP®) radiation transport code, and perform radiation transport simulations for dose calculations in MCNP®. The MCNP® code can be run natively from the PIMAL interface or externally in the MCNP® command prompt via the generated MCNP® PIMAL input file.

PIMAL 4.1.0 includes separate male and female stylized phantoms with articulated limbs and houses the International Commission on Radiological Protection (ICRP) Publication 110 reference adult male and female voxel phantoms (no articulation). Internal and external radionuclide sources can be simulated in PIMAL via a dropdown menu in the GUI, and users can select the ICRP's standard external exposure geometries or a point source from the menu options.

This user manual describes the updates to PIMAL 4.1.0, aids users in installing PIMAL, explores geometry articulation and visualization capabilities and radiation source definitions, and provides sample tutorials for PIMAL users for estimating organ doses.

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