

Integrating Sphere Tutorial

This is a general tutorial for users of TracePro and TracePro Expert.



Integrating Sphere Tutorial

Introduction

An integrating sphere is an excellent tool for producing a highly uniform distribution of light. Light rays are introduced into the interior of a spherical shell, where they repeatedly scatter until they escape through a circular exit port cut through the shell. This tutorial will show you how to:

- Create the integrating sphere with a circular exit port.
- Create a detector surface outside the exit port.
- Add a surface property to the TracePro property database.
- Assign the new surface property to the integrating sphere.
- Perform a simple raytrace with and without importance sampling.
- View the results on an irradiance map, as well as in tables.

This tutorial assumes that you are familiar with Windows.

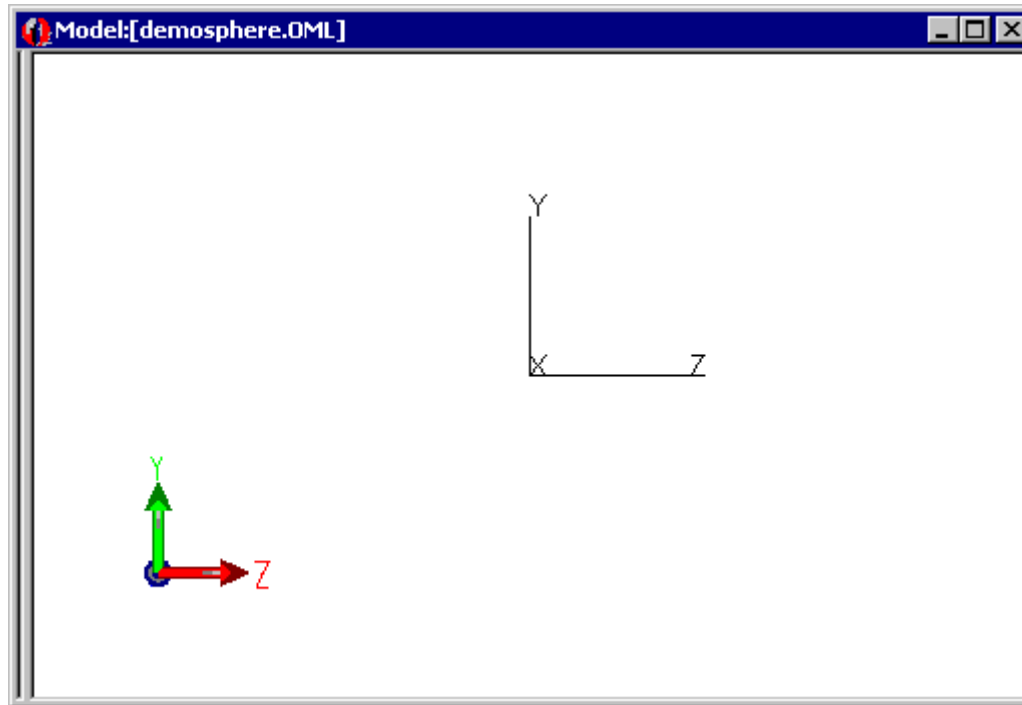
Integrating Sphere Tutorial

Initializing the Model

Start by opening a new model and applying a model name.



1. From the **File** menu in TracePro, select **New**
2. Select **File|Save As**, enter **demosphere** in the **File name** field
3. Click the **Save** button. The model window should now be titled **demosphere.OML**.

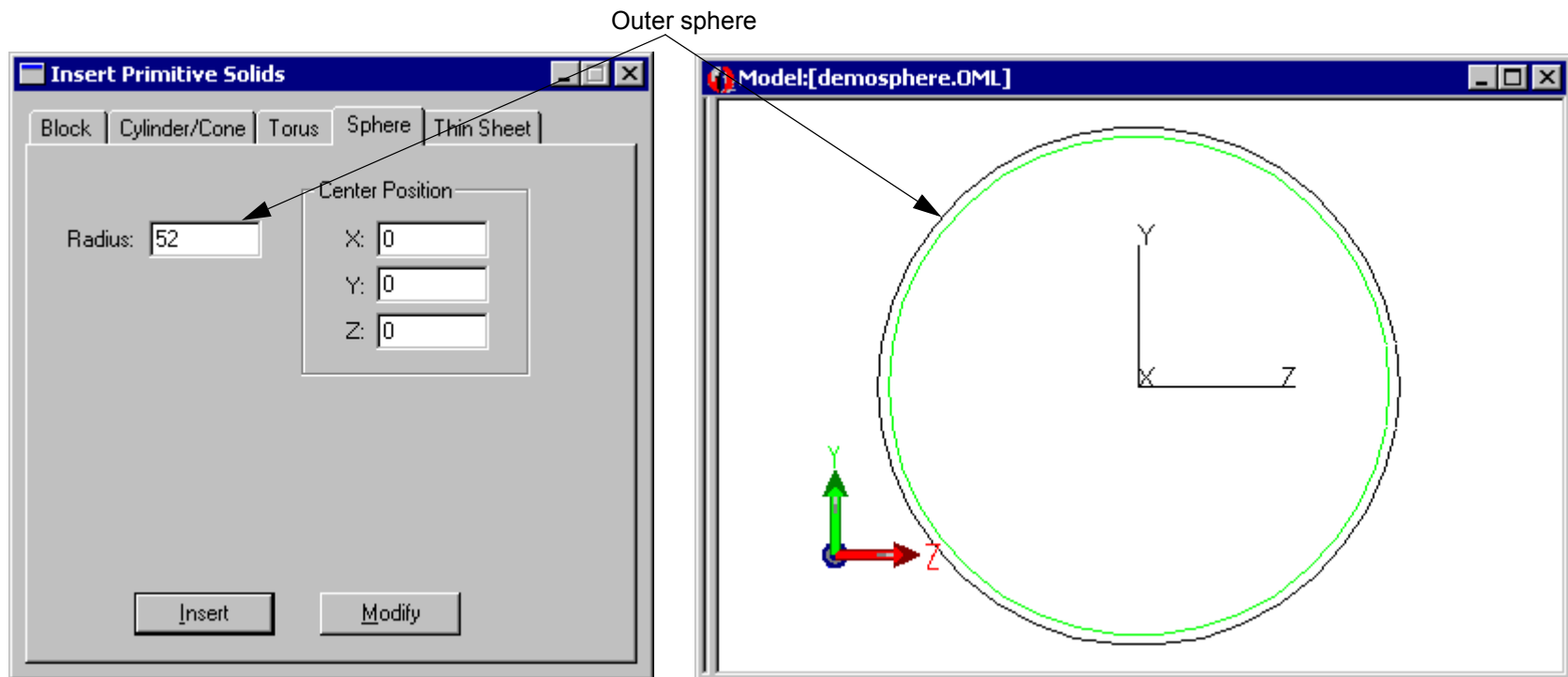


Integrating Sphere Tutorial

Creating two Spheres

You will create the spherical shell by Boolean subtraction using two concentric solid spheres. The exit port will be created by another Boolean subtraction using a circular cylinder to cut away part of the spherical shell.

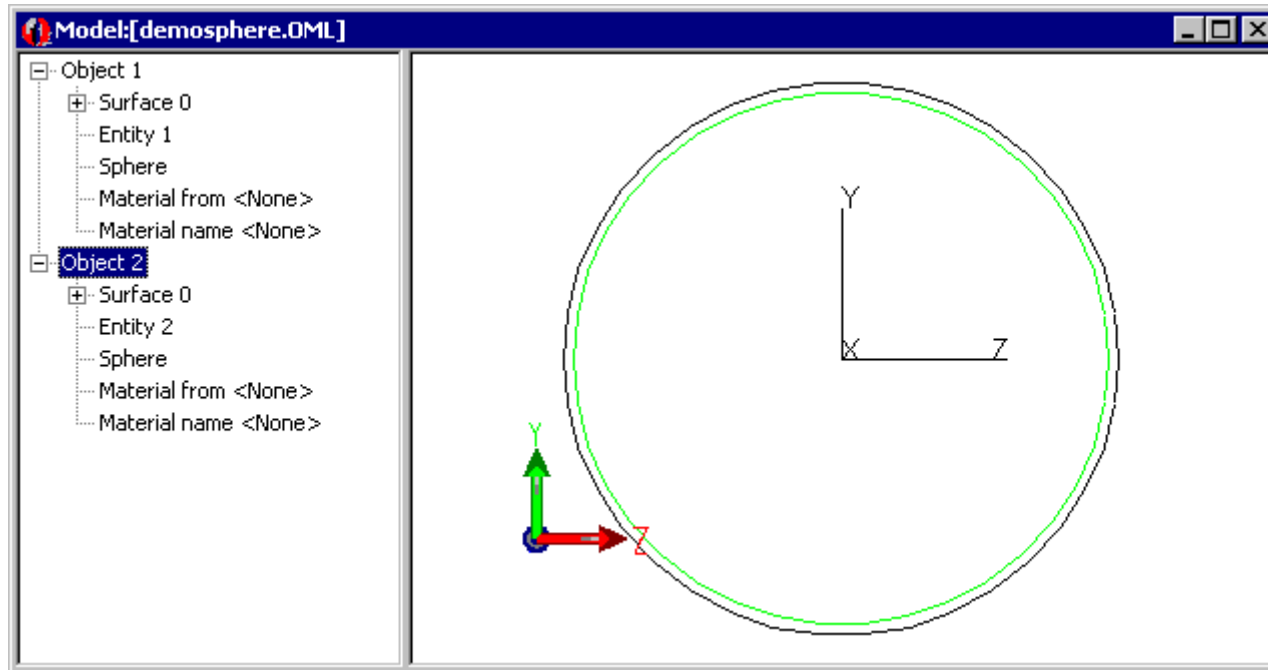
1. From the **Insert** menu select **Primitive Solid** to activate the **Insert Primitive Solids** dialog box. Click the **Sphere** tab.
2. Change the value in the **Radius** box to **50**.
3. Click **Insert** to create the inner sphere.
4. Press the Zoom All button or select the **view|Zoom|All** menu to see the new object
5. Change the value in the **Radius** box to **52** and click **Insert** again to create the outer sphere.
6. Move the **Insert Primitive Solids** dialog box out of the way (it can be left open because it is “modeless”).



Integrating Sphere Tutorial

Display the System Tree

1. Using the mouse cursor drag the left margin of the model window to the right to expose the system tree. Two objects should be listed, one for each sphere. Expand the system tree to show all information about the surfaces and materials. The model window should now appear as follows:



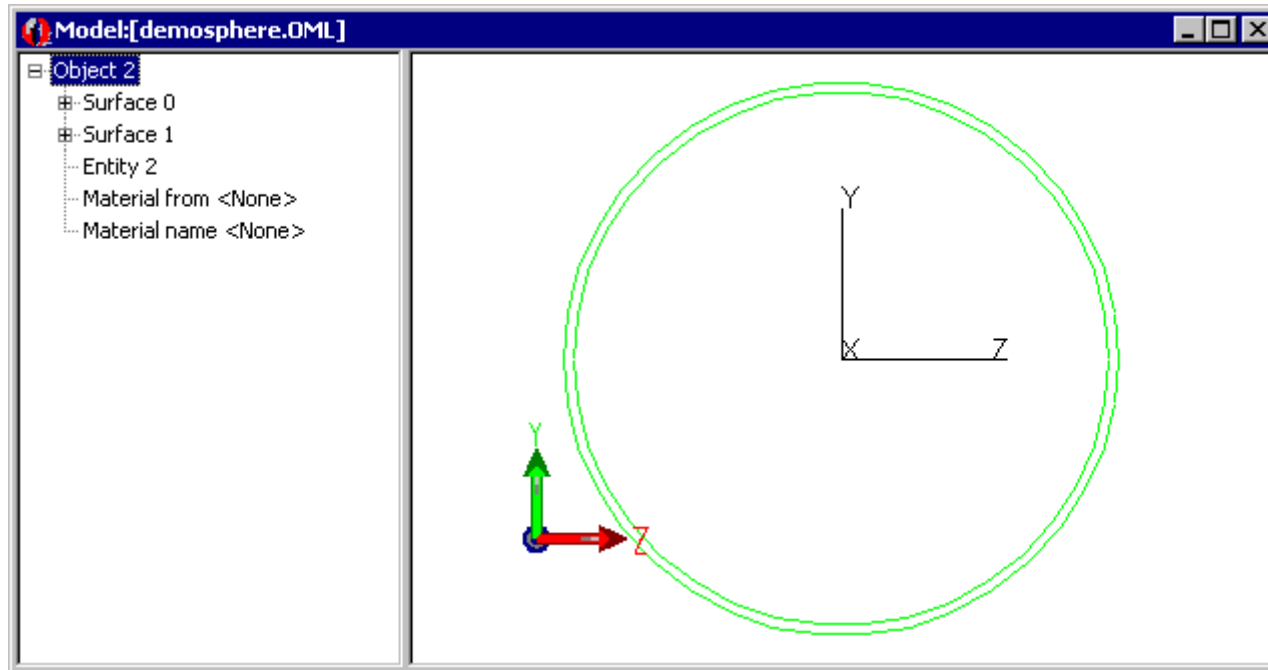
Note: If the system tree does not appear at the left, it is located at the right margin.

Integrating Sphere Tutorial

Creating the Spherical Shell

The spherical shell is made by subtracting the inner sphere from the outer sphere.

1. Select the **Edit | Select | Object** mode or press on the Select Object tool.
2. Click the silhouette (outline) of the larger sphere to select it first. Its silhouette will be highlighted.
3. Click the silhouette (outline) of the smaller sphere to while pressing the Ctrl key to add the smaller sphere to the selection. Both silhouettes will be highlighted.
4. Select **Edit | Boolean | Subtract** or click the **Subtract** button on the toolbar. The Boolean subtract command executes automatically as soon as the command is selected. The next figure shows the new contents of the model window. If you have made a mistake, click the undo button located on the toolbar



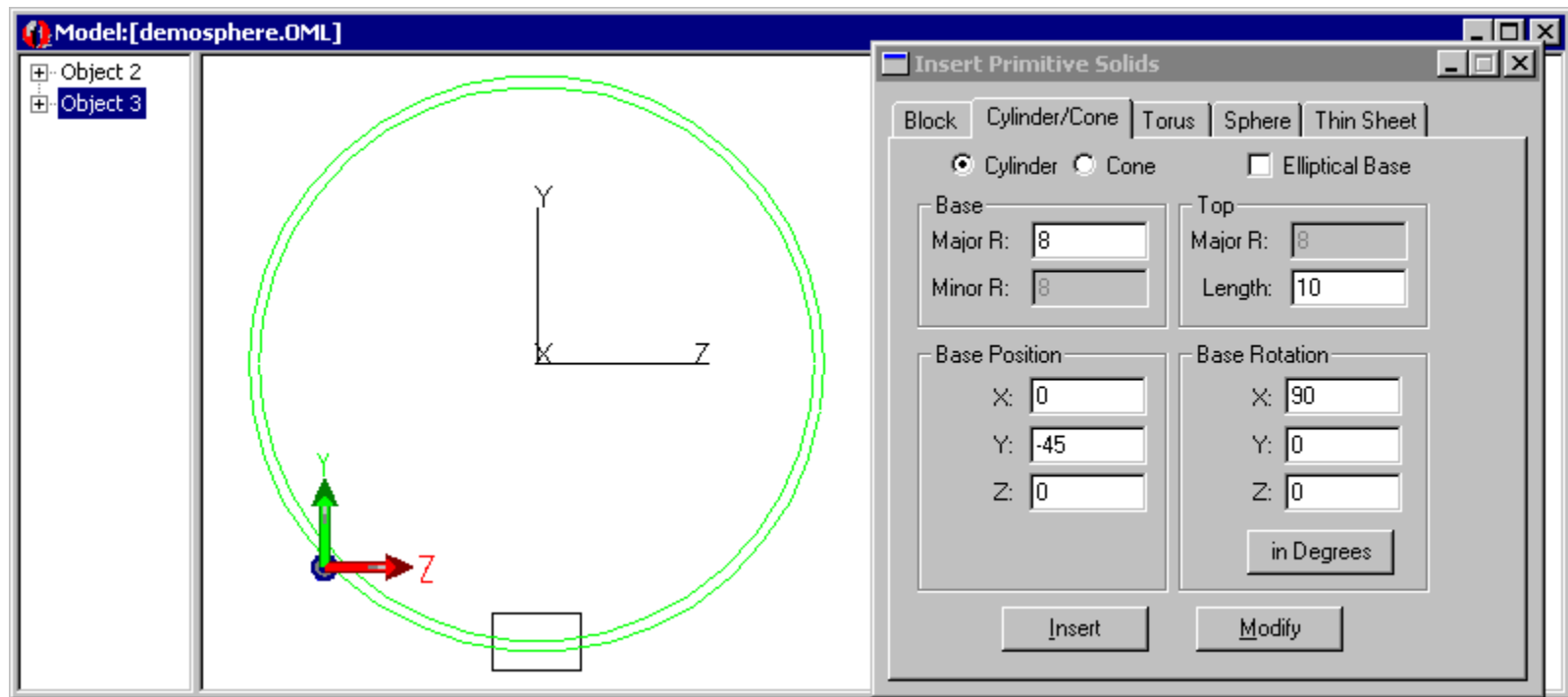
Note: In the Boolean subtraction operation, the second object selected (the **tool**) cuts away material from the first object (the **blank**) wherever the two intersect. After this operation, the modified first object is kept, while the second object is deleted automatically.

Integrating Sphere Tutorial

Add the Exit Port

The integrating sphere needs an exit port to allow light to leave the object. The exit port will be added by subtracting a cylinder from the shell.

1. Click the **Cylinder/Cone** tab in the **Insert|Primitive Solids** dialog box. Make sure that **Cylinder** (not cone) is selected, and make sure that “**Elliptical Base**” is **not** selected.
2. Change the **Y** value of the **Base** to **-45**. Change the **Major R** value of the **Base** to **8**. **Change** the **X** value of the **Base Rotation** to **90**. Change the **Length** to **10**. The **Insert Primitive Solids** dialog box should now contain the following information:



3. Click **Insert** to create the cylinder.



4. Select the spherical shell and add the cylinder with a Shift+Click. Click the **Subtract** button to perform another Boolean subtraction, it will cut material from the spherical shell, creating the circular exit port.

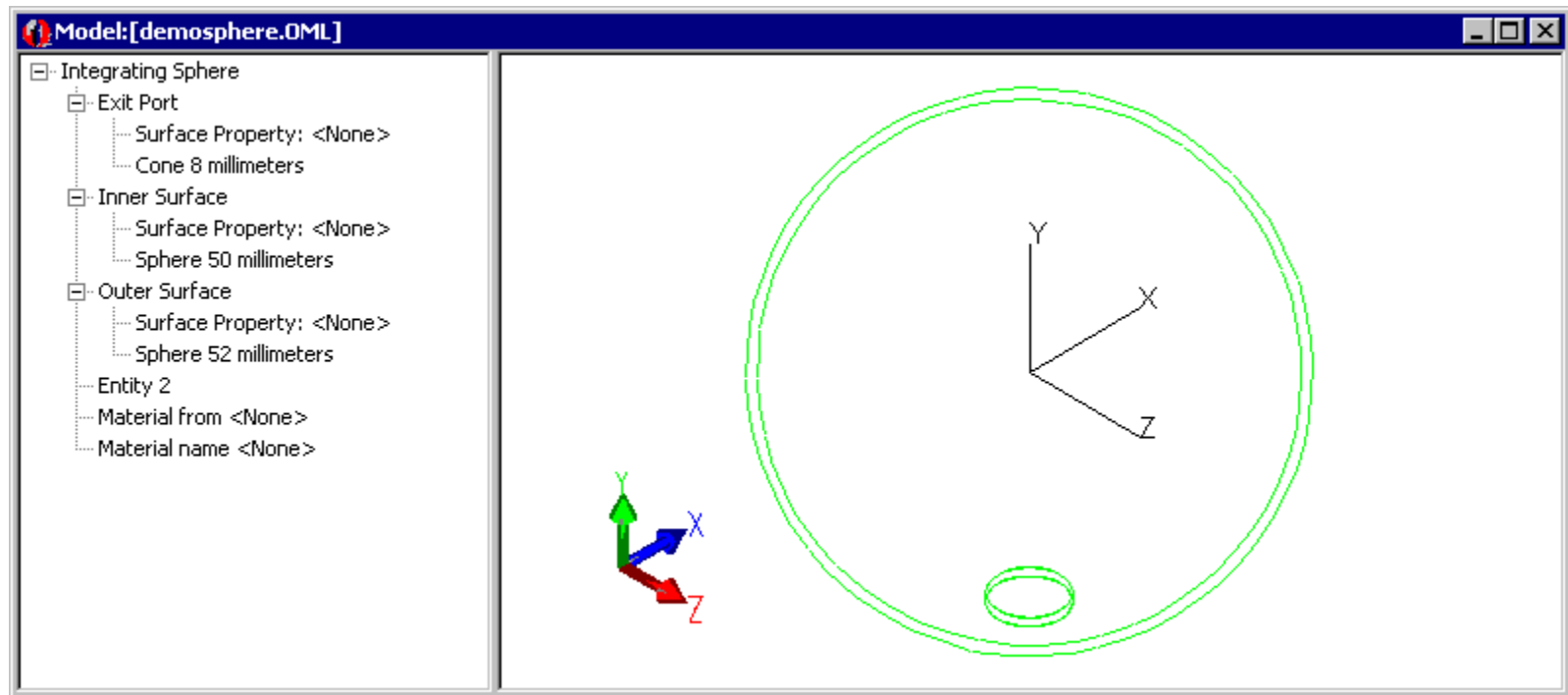
Note: When making a selection in the Model Window, Ctrl+Click and Shift+Click are equivalent.

Integrating Sphere Tutorial

Naming Objects and Surfaces

The system tree can be used to add descriptive names to objects and surfaces.

1. In the system tree there should now be only one object. Rename this object to "**Integrating Sphere**". To rename an object, highlight the original name (e.g. Object 2) and type in a new name. Note that objects and surfaces being renamed are highlighted in the model window.
2. Rename the inner and outer surfaces of the integrating sphere in the system tree to "**Inner Surface**" and "**Outer Surface**", respectively. Rename the cylindrical surface (specified in the system tree as a "Cone") of the exit port to "**Exit Port Surface**".
3. Click the **save** button on the toolbar (or select **File | Save**) to save the model at this stage.
4. Click the **Iso View 1** button on the toolbar to get a better view of the circular exit port. The following figure shows the new contents of the model window with the system tree expanded.

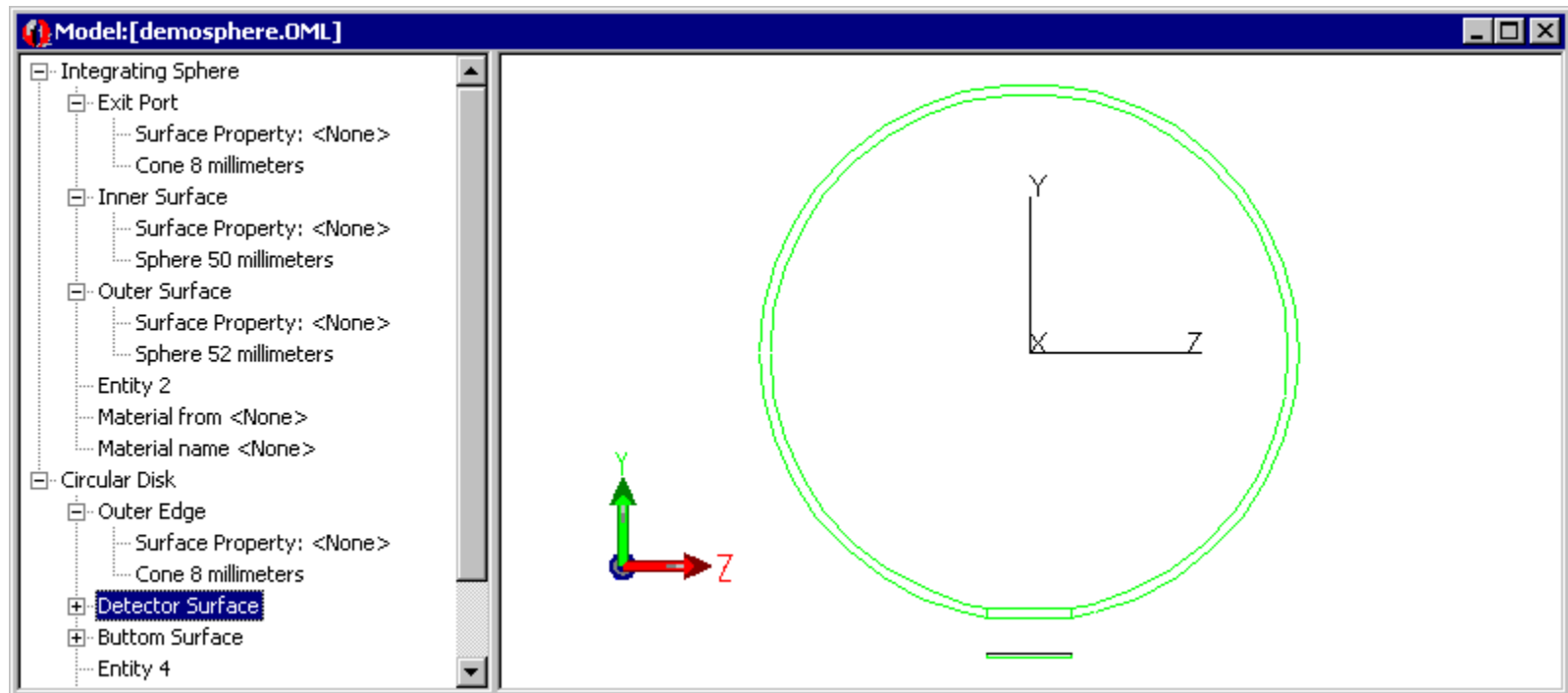


Integrating Sphere Tutorial

Creating the Detector Surface

The detector surface will be the top surface of an 8mm diameter thin circular disk located opposite the exit port. To create the detector surface:

1. Click the **YZ** view button on the toolbar to change views back to the original.
2. Click the **Cylinder/Cone** tab in the **Insert|Primitive Solids** dialog box. Make sure that **Cylinder** (not cone) is selected, and make sure that "**Elliptical Base**" is **not** selected.
3. Change the **Y** value of the **Base** to **-58**. Keep the **Major R** value of the **Base** equal to **8**. Change the **Length** value to **1**.
4. Click **Insert** to create the disk, and close the **Insert|Primitive Solids** dialog box.
5. Rename this new object "**Circular Disk**". Rename its "**Cone**" surface to "**Outer Edge**", its "**Surface 1**" (top) to "**Detector Surface**", and its "**Surface 2**" (bottom) to "**Bottom Surface**".
6. Click the **Zoom All** button on the toolbar to rescale the objects in the model window.

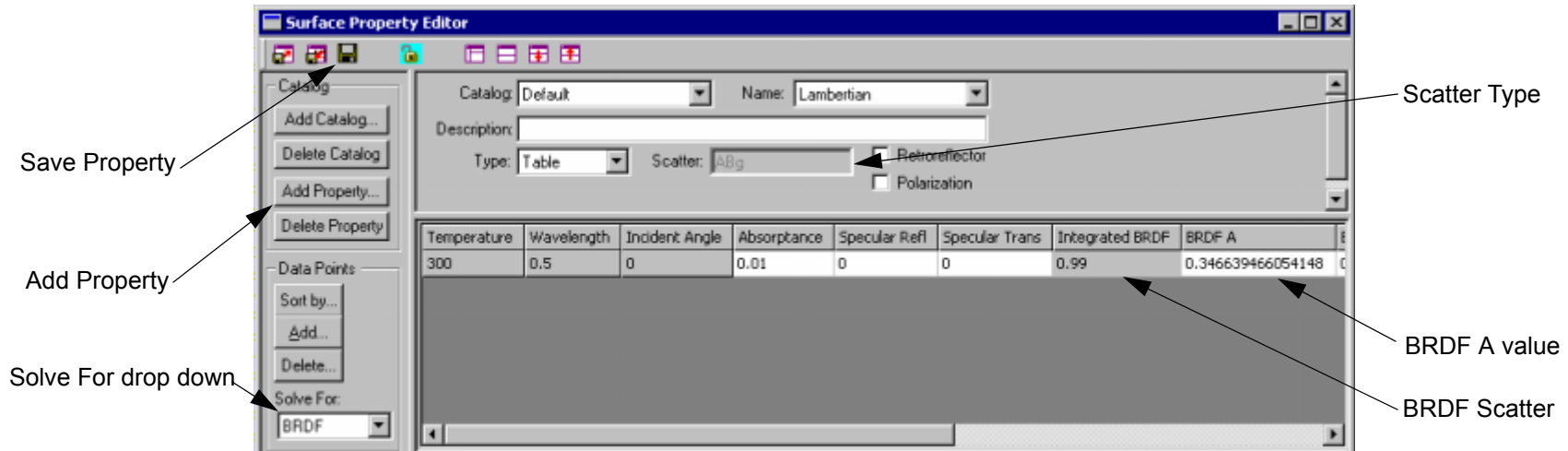


Integrating Sphere Tutorial

Adding A Surface Property to the Database

TracePro has a **Surface Property Editor** that can be used to add new surface properties to the database or modify the existing ones. You will use this editor to define a new property named “Lambertian” that scatters light diffusely (in a Lambertian distribution) and absorbs 1% of the incident light. TracePro enforces conservation of energy, which means that the sum of the absorbed, reflected and transmitted light must equal the incident light at a surface. Whenever surface property data are created or modified they are checked for conservation of energy. To assist the user, TracePro offers the “**Solve for**” command that can be used for automatic calculation of surface properties to assure conservation of energy. You will use the “**Solve for**” command to correct the Lambertian value for BRDF A. To define the new surface property:

1. Point to From the **Define** menu, select **Edit Property Data|Surface Properties**. This will open the **Surface Property Editor**. Click **Add Property**.
2. Enter **Lambertian** into the **Surface Property Name** field, select **ABg scatter model** and click the **OK** button. This will return you to the **Surface Property Editor** dialog box with default numerical values in the fields.
3. Click the **absorptance** data field and enter the value **0.01** into the field.
4. From the **Solve for** drop-down list click **BRDF** to calculate the correct value for BRDF A (=0.346639) and automatically insert it into the field, as shown below.
5. From the **File** menu click **save** and then **Close** to save the surface property data to the TRACEPRO.MDB database file and then return to the model window.



Note: The Lambertian surface property values have only been defined for a single angle of incidence. TracePro will use these values for all angles unless additional angles are defined, in which case TracePro will use linear interpolation to obtain data for intermediate angles.

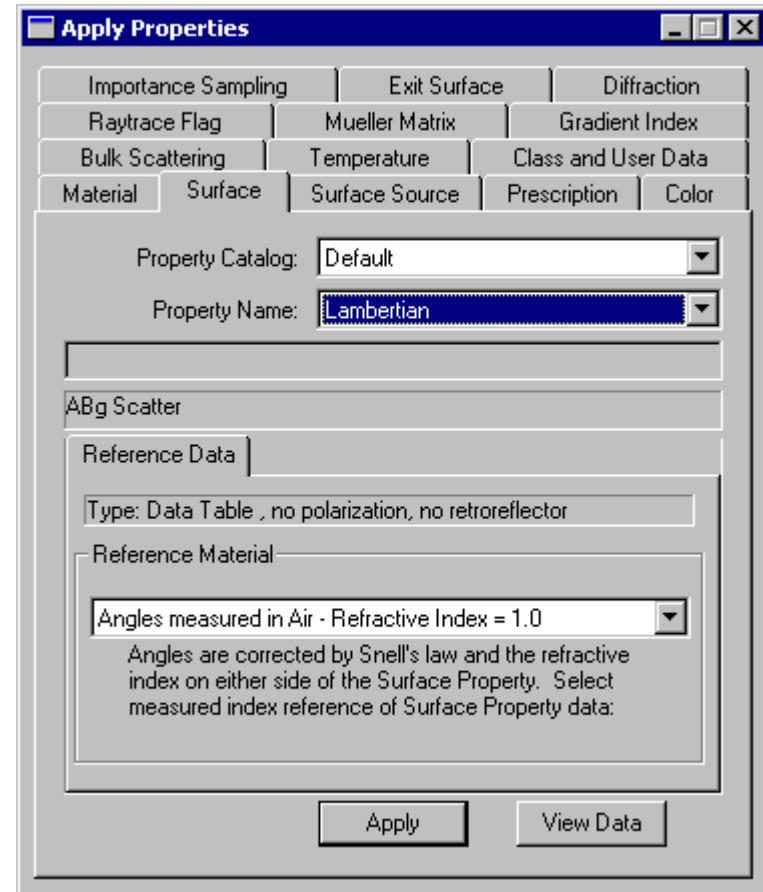
Integrating Sphere Tutorial

Assigning the New Surface Property to the Integrating Sphere

At this point the necessary geometrical objects have been created and Lambertian has been added to the surface property database. The next step is to assign the Lambertian surface property to the inside of the integrating sphere, as follows:



1. Click the **Select Surface** button on the toolbar.
2. Select the inner surface of the integrating sphere by clicking its name in the system tree.
3. From the **Define** menu select **Apply Properties**.
4. Click the **Surface** tab.
5. From the **Surface Property Name** drop-down list select **Lambertian**.
 - The figure shows the **Apply Properties** dialog box at this point.
6. Click the **Apply** button.
7. Check in the system tree that the Inner Surface of the Integrating Sphere was assigned the **Lambertian** surface property.
8. Close the **Apply Properties** dialog box.
9. Click the **Select Surface** button on the toolbar to toggle it off.

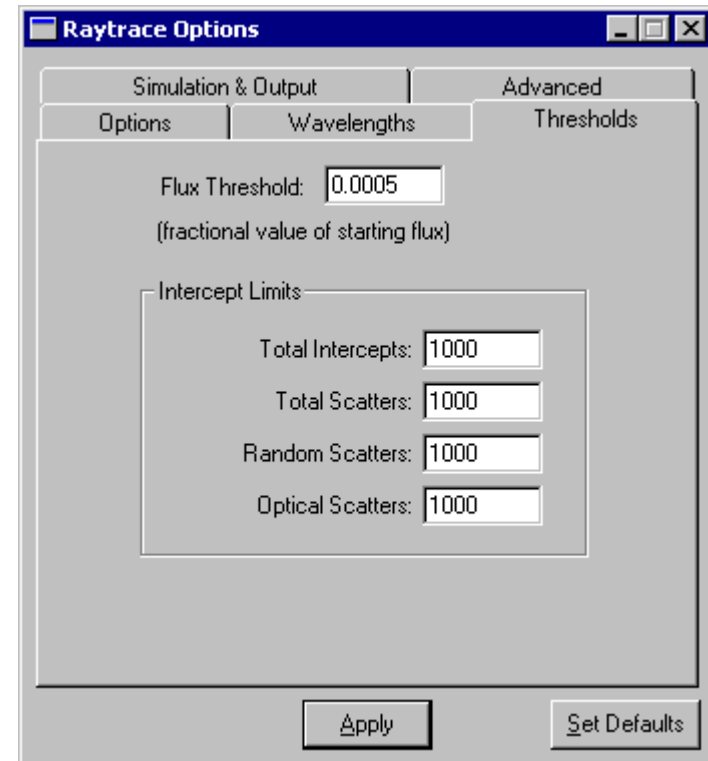


Integrating Sphere Tutorial

Setting Raytrace Thresholds

Before tracing any rays you will redefine the **flux threshold**. The default value is 0.05, which means that as rays bounce around and split into more rays, the new rays with less than 5% of the starting flux will no longer be traced. In order to generate a significant number of rays exiting the integrating sphere you should decrease this threshold to 0.0005

1. From the **Analysis** menu select **Raytrace Options**.
2. Click the **Thresholds** tab and enter a value of **0.0005** for **Flux Threshold** as shown.
3. Click **Apply** and close the **Raytrace Options** dialog box.

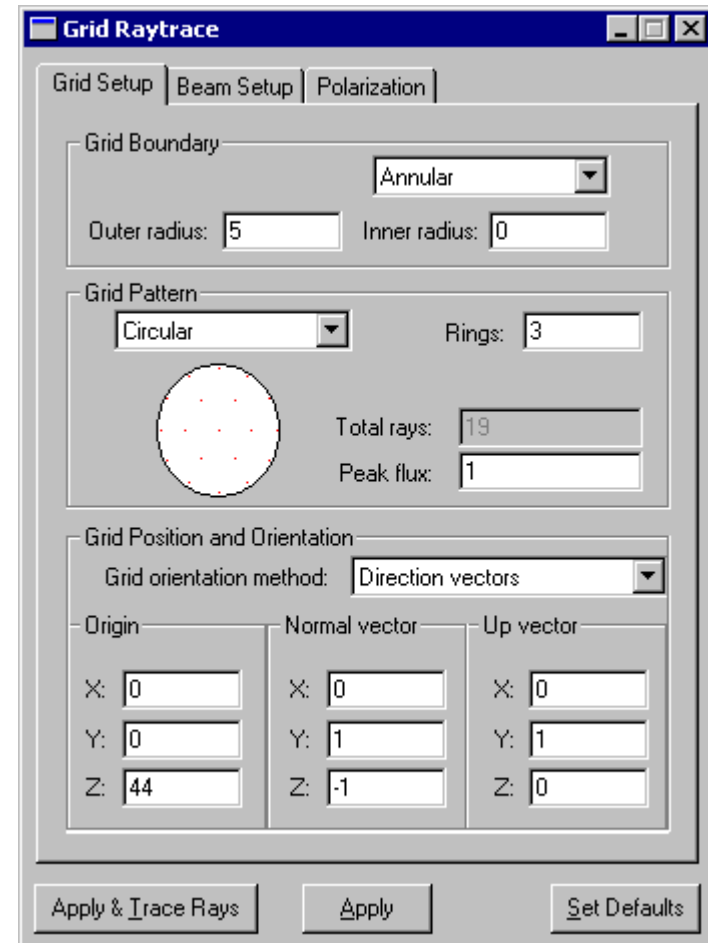


Integrating Sphere Tutorial

Tracing Rays

In this example you will trace rays from a circular grid. The actual number of rays traced will be determined when you specify a **Rings** value for the grid, i.e. the number of rings making up the circular grid of starting points. In this case you will use a **Rings** value of 3, which corresponds to 19 starting rays. The rays will start inside the sphere at a 45° angle.

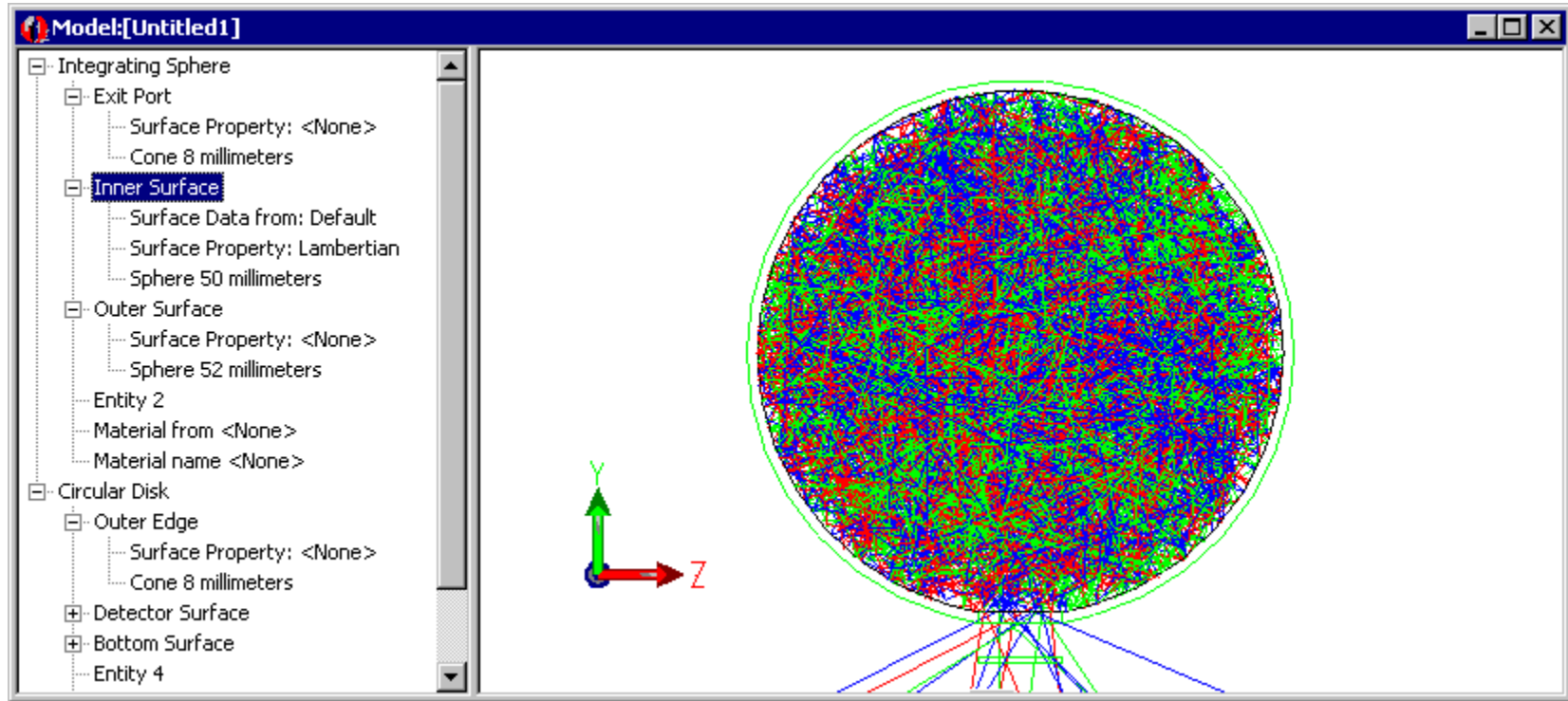
1. From the **Analysis** menu select **Grid Raytrace**, click **Grid Setup**, bringing up the **Grid Raytrace** dialog box.
2. With **Annular** selected for the **Grid Boundary** enter **5** for the **Outer radius**, and keep the **Inner radius** equal to **0**.
3. With **Circular** selected for the **Grid Pattern** enter **3** for the **Rings** value.
4. For the **Origin** change the **Z** value to **44**, leaving the **X** and **Y** components equal to **0**.
5. For the **Normal Vector** change the **Y** and **Z** component values to **1** and **-1**, respectively, leaving the **X** component equal to **0**.
6. Leave the **Up vector X, Y, and Z** components equal to **0, 1, and 0**, respectively.
7. The **Grid Raytrace** dialog box should now appear as follows:
8. Click the **Apply & Trace Rays** button. This will start an audit of the model, followed by the specified raytrace. A total of 19 rays will be traced.
9. When the raytrace has finished, close the **Grid Raytrace** dialog box.



Integrating Sphere Tutorial

Raytrace Results

The following figure shows the model window after the **Grid Raytrace** has finished. Note how the interior of the integrating sphere is filled with rays, with a few rays escaping through the exit port.

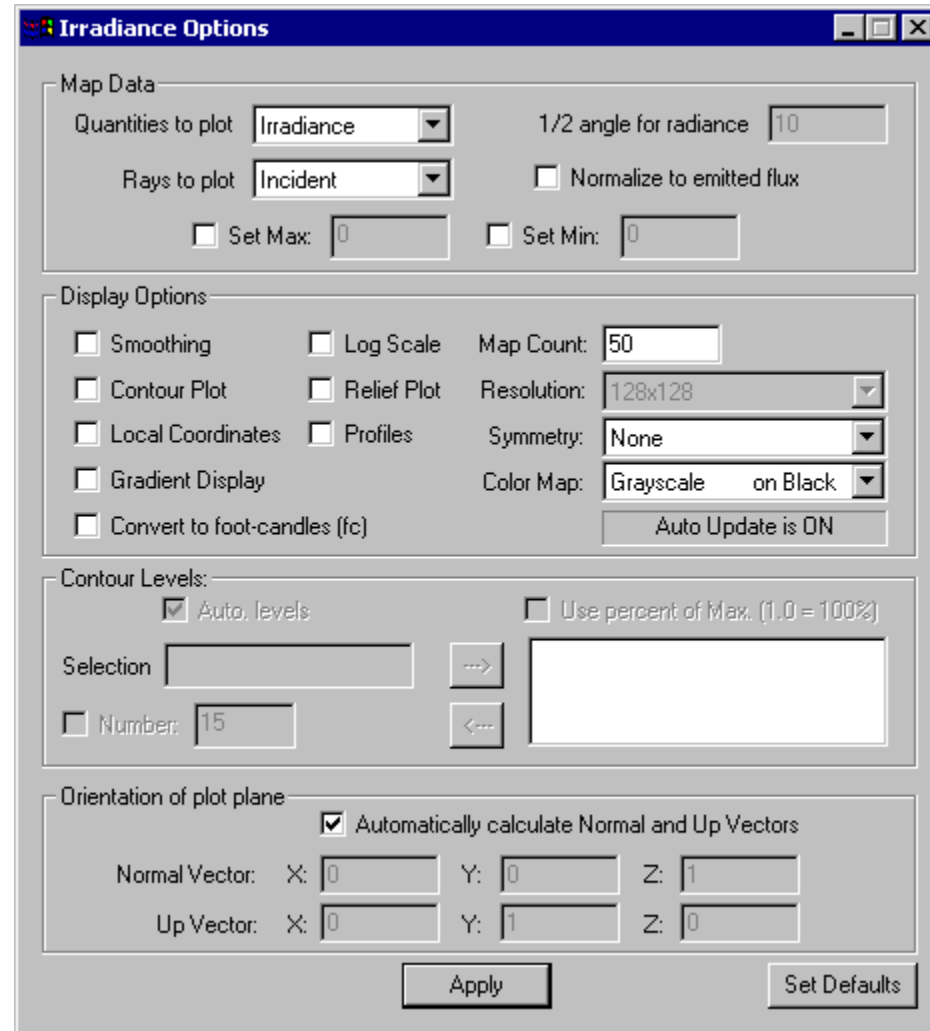


Integrating Sphere Tutorial

Setting the Irradiance Map Options

To create an irradiance map to view the flux incident on the detector surface, do the following:

1. Select the Detector Surface from the Model Window or System Tree.
2. From the **Analysis** menu select **Irradiance/Illuminance options** and make the following entries in the dialog box.
3. For **Map Type** select **Incident** in the **Irradiance** drop-down list.
4. For **Display** select **Grayscale on Black** from the **Color Map** drop-down list.
5. Click the “**Automatically calculate Normal and Up Vectors**” box.
6. The **Irradiance Options** dialog box should match the dialog shown:
7. Click **Apply** and move the **Irradiance Options** dialog box out of the way.



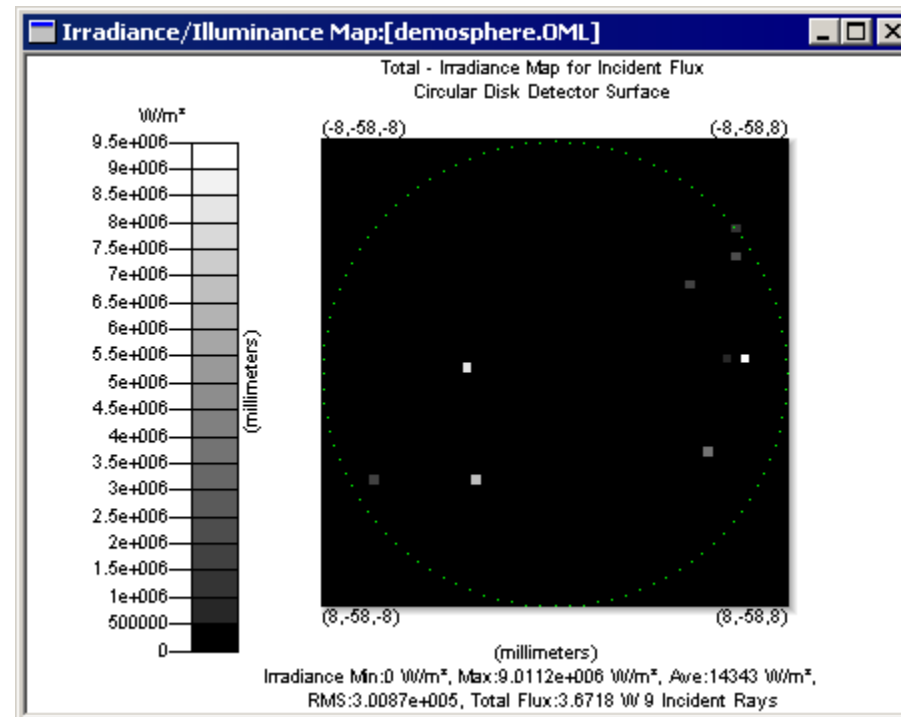
Integrating Sphere Tutorial

Viewing the Irradiance Map



An Irradiance Map can be displayed for any surface in the mode by selecting a desired surface and open the plot.

1. Click the **Select Surface** button on the toolbar.
2. Click to select the Detector Surface in the system tree.
3. From the **Analysis** menu select **Irradiance/Illuminance Maps** to create the irradiance map. It is shown in the following figure.



Rays intercepting the detector surface are visible as white or gray spots in the irradiance map. Although eight rays have intercepted the detector surface, only seven are visible in the irradiance map because the eighth has a low flux level.

To view these results in false color:

1. Select **Color (rainbow) on Black** from the **Color Map** drop-down list in the **Irradiance/Illuminance Options** dialog box and click **Apply**.
2. Close the **Irradiance/Illuminance Options** dialog box.

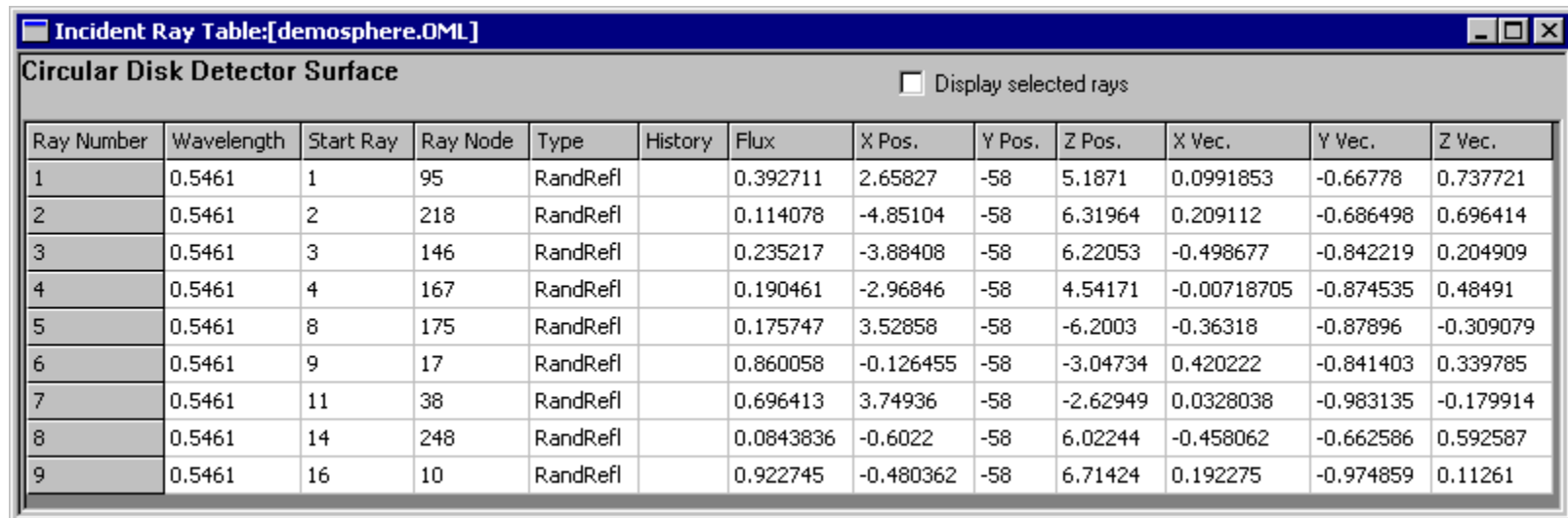
Integrating Sphere Tutorial

Viewing the Incident Ray Table

To view a table of the rays striking the detector surface, do the following:

1. From the **window** menu select **Model : [demosphere.OML]** to return to the model window.
2. If the detector surface is not selected (highlighted) in the system tree, select it now by clicking on it in the system tree or the model window.
3. From the **Analysis** menu select **Incident Ray Table**.
4. You can also select from the **View** menu select **Auto Size**.

The following figure shows a portion of the table that should be obtained. Note that 9 rays are listed, corresponding to the 9 rays shown in the **Irradiance/Illuminance Map**.



Ray Number	Wavelength	Start Ray	Ray Node	Type	History	Flux	X Pos.	Y Pos.	Z Pos.	X Vec.	Y Vec.	Z Vec.
1	0.5461	1	95	RandRefl		0.392711	2.65827	-58	5.1871	0.0991853	-0.66778	0.737721
2	0.5461	2	218	RandRefl		0.114078	-4.85104	-58	6.31964	0.209112	-0.686498	0.696414
3	0.5461	3	146	RandRefl		0.235217	-3.88408	-58	6.22053	-0.498677	-0.842219	0.204909
4	0.5461	4	167	RandRefl		0.190461	-2.96846	-58	4.54171	-0.00718705	-0.874535	0.48491
5	0.5461	8	175	RandRefl		0.175747	3.52858	-58	-6.2003	-0.36318	-0.87896	-0.309079
6	0.5461	9	17	RandRefl		0.860058	-0.126455	-58	-3.04734	0.420222	-0.841403	0.339785
7	0.5461	11	38	RandRefl		0.696413	3.74936	-58	-2.62949	0.0328038	-0.983135	-0.179914
8	0.5461	14	248	RandRefl		0.0843836	-0.6022	-58	6.02244	-0.458062	-0.662586	0.592587
9	0.5461	16	10	RandRefl		0.922745	-0.480362	-58	6.71424	0.192275	-0.974859	0.11261

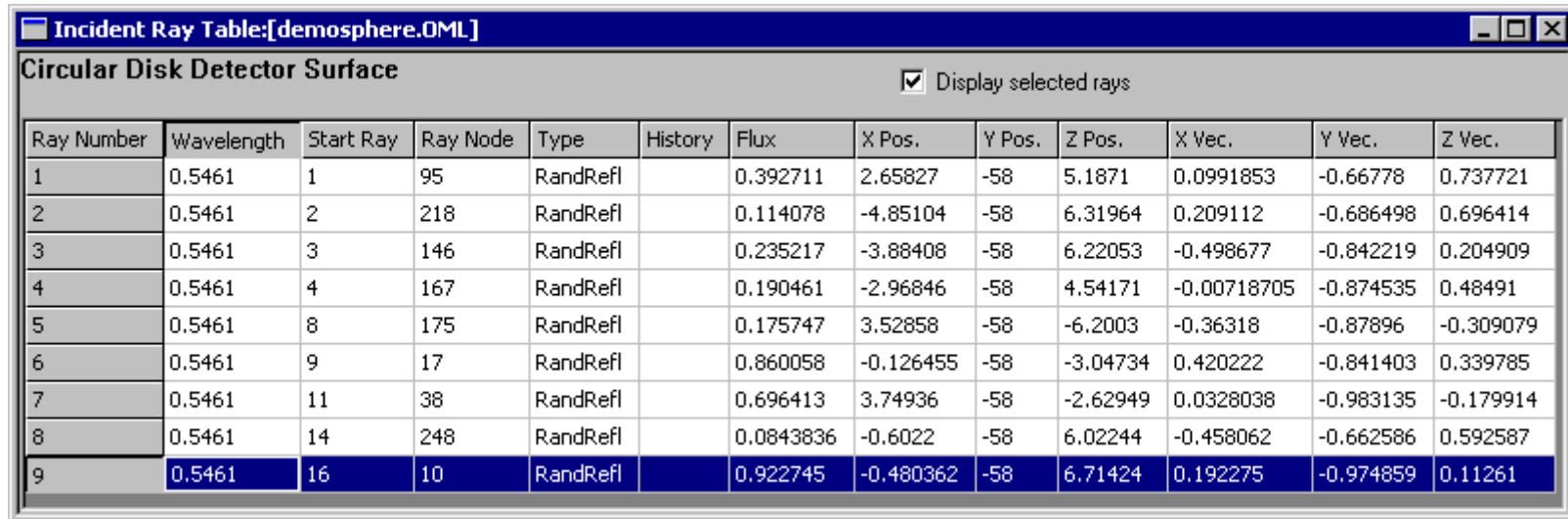
Integrating Sphere Tutorial

Viewing a individual Incident Rays

From the Incident Ray table, one or more rays can be selected and displayed in the Model Window.

1. Select **Display selected rays** from within the Incident Ray Table.

Select one of the rows in the table. Selecting Ray Number 9 will shown a ray with only 10 bounces in the sphere since the Ray Node corresponds to the intersection number.



Incident Ray Table:[demosphere.OML] Display selected rays

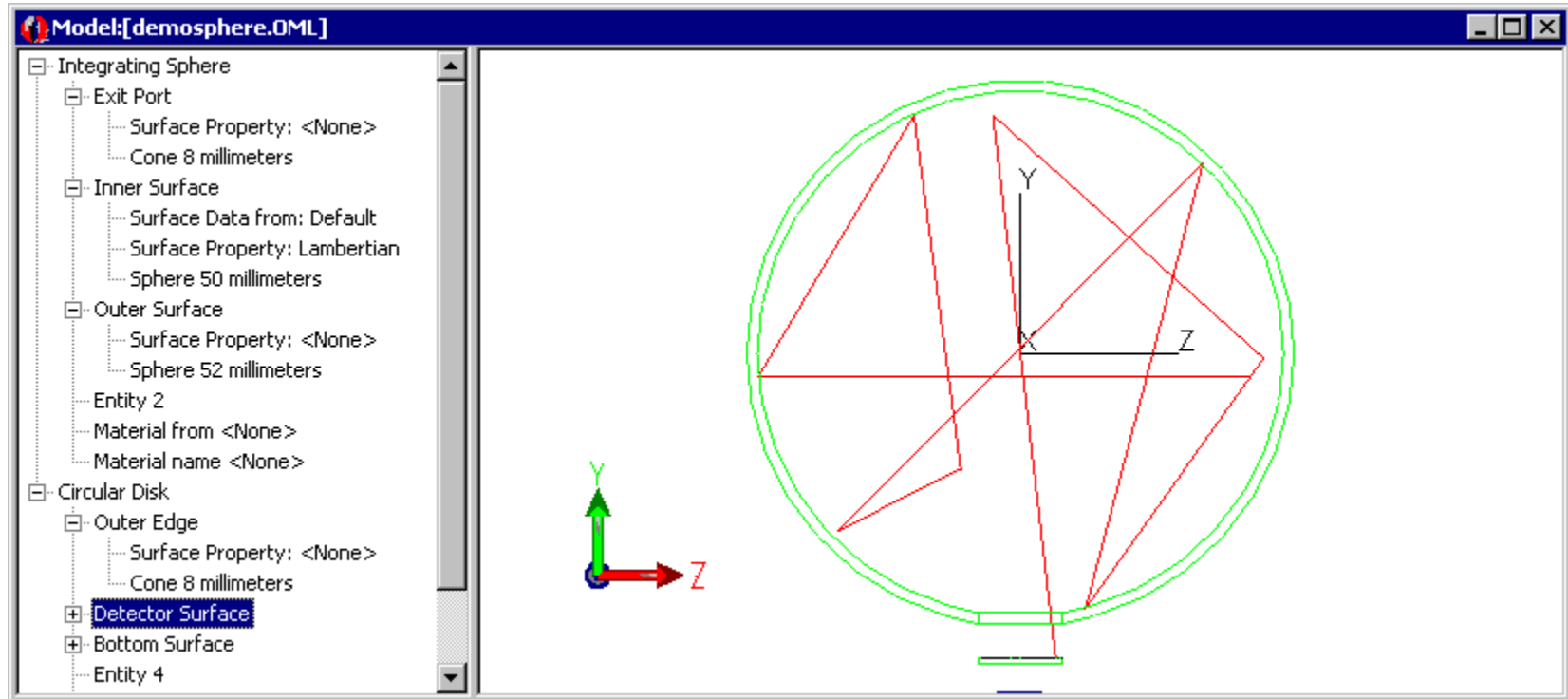
Ray Number	Wavelength	Start Ray	Ray Node	Type	History	Flux	X Pos.	Y Pos.	Z Pos.	X Vec.	Y Vec.	Z Vec.
1	0.5461	1	95	RandRefl		0.392711	2.65827	-58	5.1871	0.0991853	-0.66778	0.737721
2	0.5461	2	218	RandRefl		0.114078	-4.85104	-58	6.31964	0.209112	-0.686498	0.696414
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8	0.5461	14	248	RandRefl		0.0843836	-0.6022	-58	6.02244	-0.458062	-0.662586	0.592587
9	0.5461	16	10	RandRefl		0.922745	-0.480362	-58	6.71424	0.192275	-0.974859	0.11261

Integrating Sphere Tutorial

Viewing a individual Incident Rays (con't)

The Model Window will be updated to show the selected ray.

Be sure to Un-select **Display selected rays** to restore the ray display.

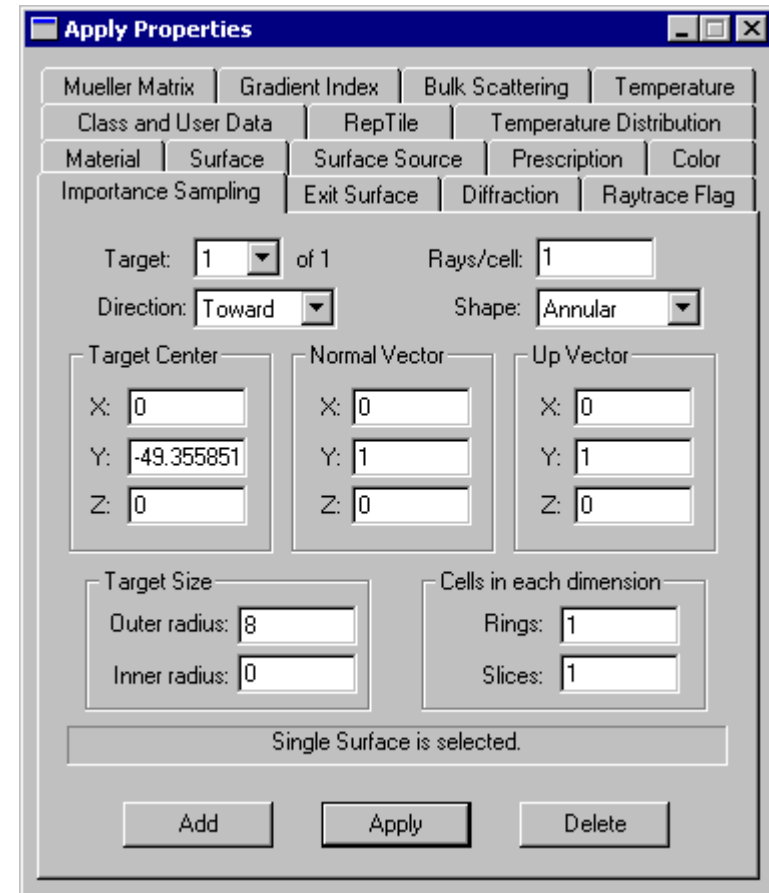


Integrating Sphere Tutorial

Adding Importance Sampling

“Importance sampling” is a technique in which scattered (and diffracted) rays are generated and transmitted towards specific “targets” in the optical system that are considered “important.” This improves sampling by increasing the number of rays going in a direction that is important to you. This technique can be especially helpful in stray light analysis where the attenuation of incident light may be very great. In this tutorial you will add one importance sampling target to the model. Its location, orientation, shape, and size will be specified to match the exit port. This will increase the number of rays hitting the detector surface, while the flux of each ray will be smaller. The same total flux will hit the detector surface as before, but spread over many more rays, giving a better picture of the distribution of light at the detector surface.

1. Make room on your screen by closing the **Irradiance/ Illuminance Map** window and the **Incident Ray Table** window, as well as any other open dialog boxes.
2. Be sure the **Select Surface** button on the toolbar is depressed.
3. Select the **Inner Surface** of the **Integrating Sphere**.
4. From the **Define** menu select **Apply Properties**.
5. Click the **Importance Sampling Tab** in the **Apply Properties** dialog box and click **Add**.
6. For **Target 1** change the **Target Center Y** value to **-49.355851**, change the **Normal Vector Y** value to **1**, and change the **Radius Outer** value to **8** as shown. The **Up Vector** is used for Rectangular Targets and can be ignored in this case.
7. Click **Apply**.
8. Check the system tree to verify that an **Importance Target** has been defined on the **Inner Surface** of the **Integrating Sphere**.
9. Close the **Apply Properties** dialog box.

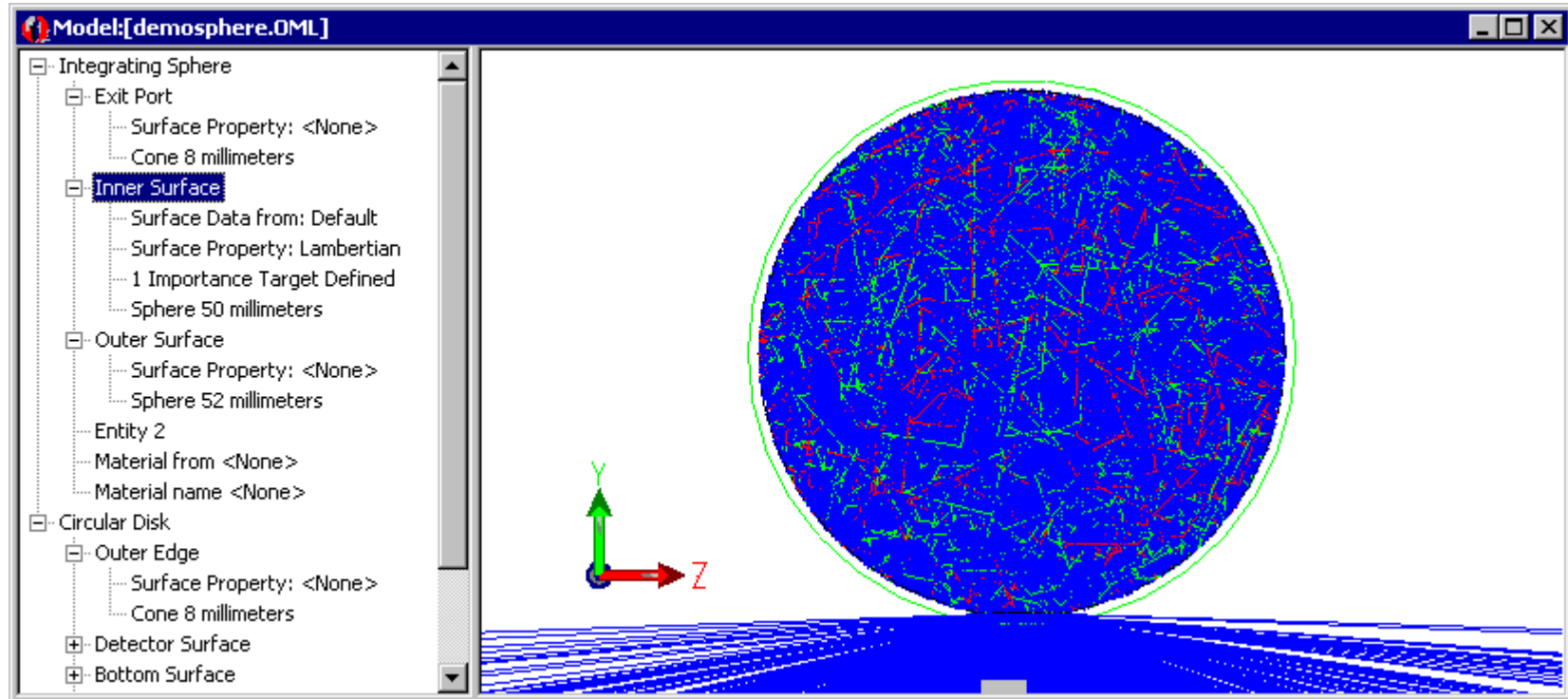


Integrating Sphere Tutorial

Raytrace with an Importance Target

Click the **Grid Trace** button on the toolbar to start the ray trace calculations. Depending on your computer's speed, this analysis can take many minutes or more.

The figure shows the grid raytrace with importance sampling turned on.

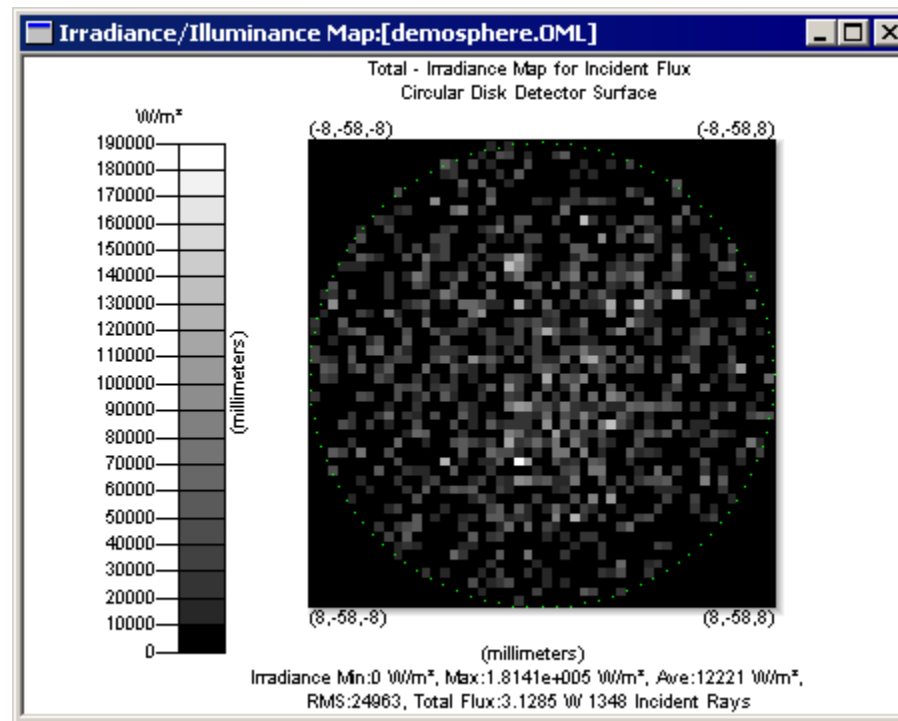


Integrating Sphere Tutorial

Irradiance Map with Importance Sampling

Now you can view the updated irradiance map.

1. Click to select the Detector Surface in the system tree. It will be highlighted in blue.
2. From the **Analysis** menu select **Irradiance/Illuminance Maps**.
3. The following figure shows the resulting irradiance map. Note that many rays have now intercepted the detector surface, and they are uniformly distributed over the surface.



Note: You can apply smoothing or increase the number of rays to improve the ray sampling in the plot.

Integrating Sphere Tutorial

Arranging Views

Sometimes it is useful to display multiple views simultaneously. For example, with the model, system tree and irradiance map views open together, you can select different surfaces on the system tree and automatically see the flux incident on them as well as their highlighted location in the model view. You can also include the ray histories view which will also update as you choose different surfaces. To arrange these views do the following



1. From the **window** menu select **Tile Vertical**. You can Resize the different windows to your liking.

