Integrating Sphere

Requirements

Models: None

Properties: None

*Editions:*   TracePro Standard and Expert

Introduction

An integrating sphere can be used to make a highly uniform light source. The source can be uniform both spatially and angularly. Integrating spheres are also used to measure many types of light sources, including LEDs. To model an integrating sphere, light rays are introduced into the interior of a spherical shell. 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.

Creating Two Spheres

Create the integrating sphere shell using Boolean subtraction with 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. Start with an empty model in TracePro.
2. Select **View|Silhouettes** to get the view shown below.
3. Select **Geometry|Primitive Solid** and select the *Sphere* tab.
4. Enter 50 for the Radius and click *Insert*.
5. Press the **Zoom All** icon in the View Toolbar, or select **View|Zoom|All** to see the new object.
6. Change the value in the *Radius* box to 52 and click *Insert* again to create the outer sphere.
7. Move the *Insert Primitive Solids* dialog box out of the way.

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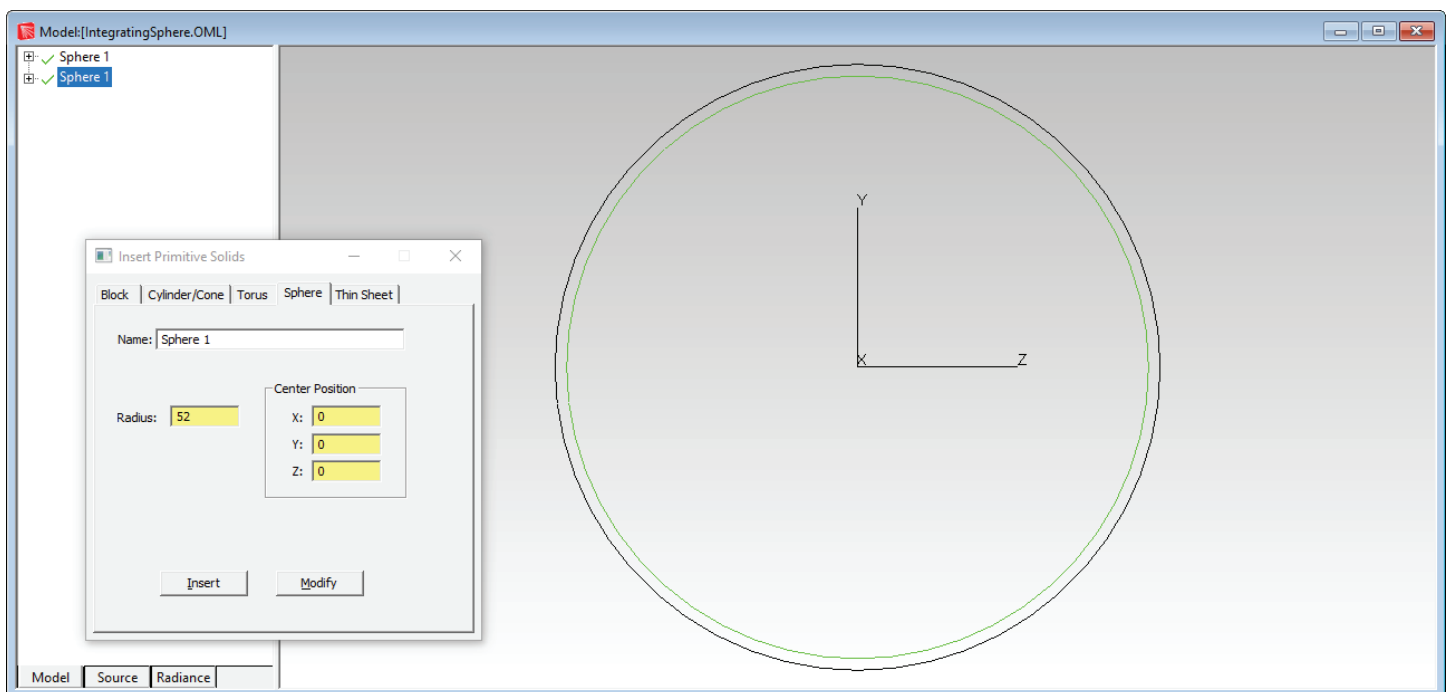
Creating the Spherical Shell

Make the spherical shell by subtracting the inner sphere from the outer sphere.

1. Select the **Edit|Select|Object**.
2. Click the silhouette of the larger sphere to select it first. Its silhouette will be highlighted.
3. Ctrl-click the silhouette of the smaller sphere to add it 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.
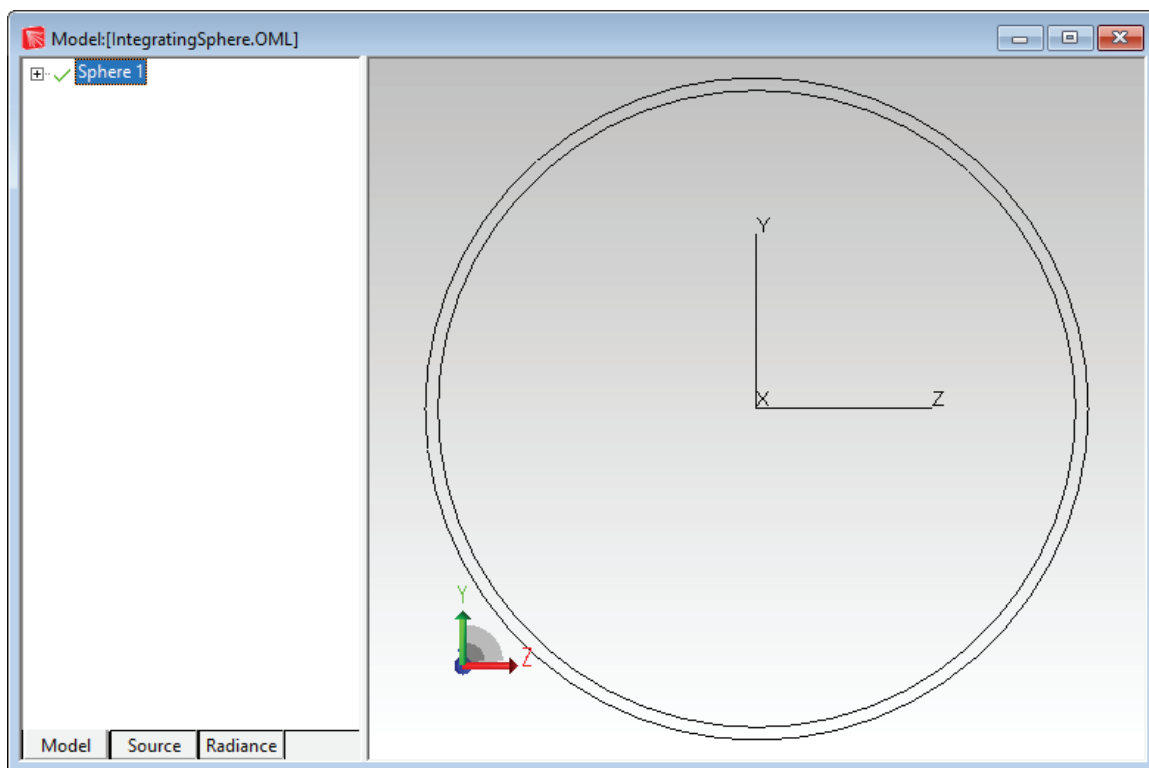

****Note:** In the Boolean subtraction operation, the second object selected (the **tool**) cuts away material from the first object (the **blank**) wherever the two intersect. After this operation, the modified first object is kept, while the second object is deleted.

Add the Exit Port

The integrating sphere needs an exit port to allow light to escape. The exit port will be added by subtracting a cylinder from the shell.
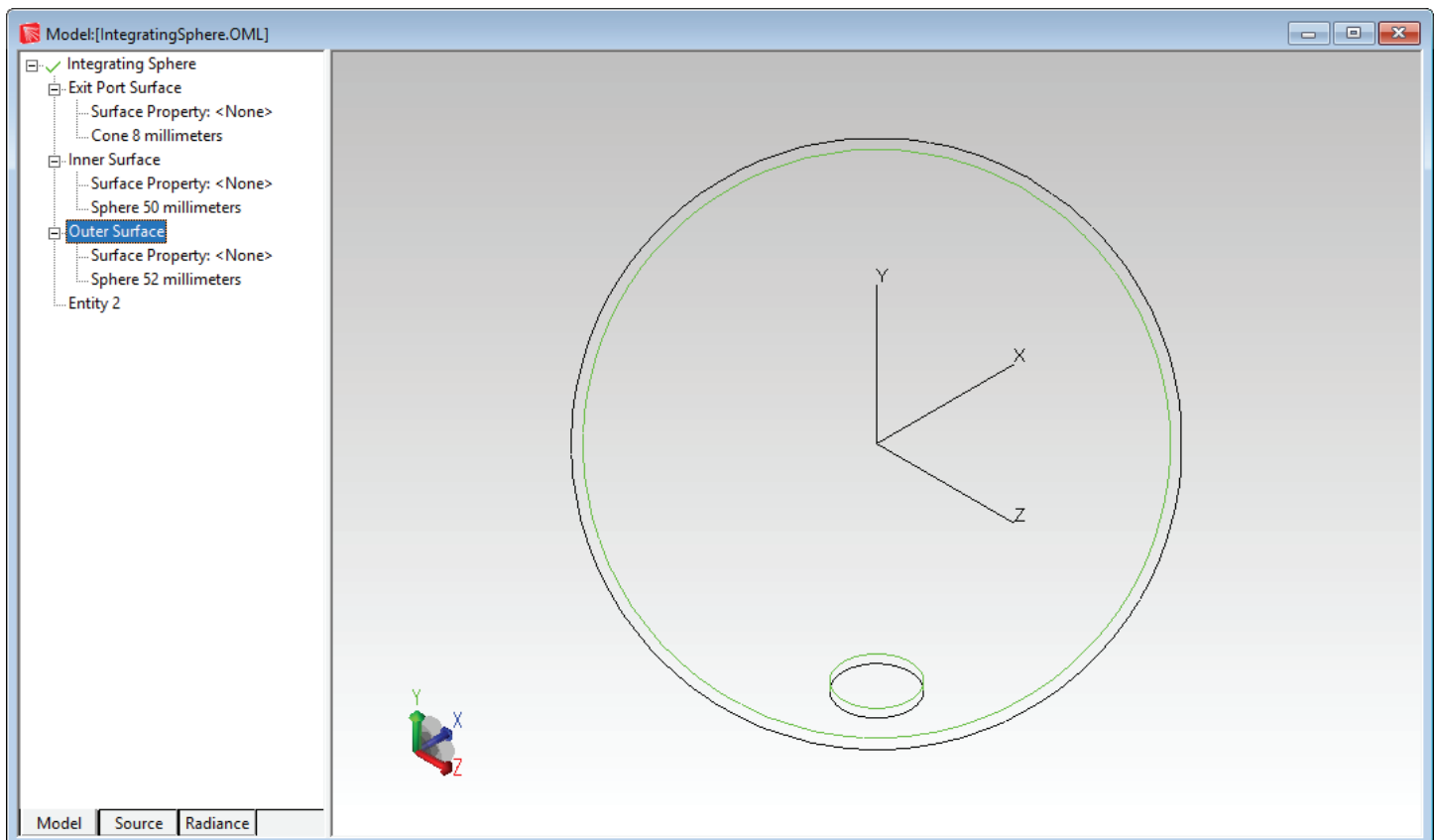
1. Select the *Cylinder/Cone* tab in the **Insert|Primitive Solids** dialog box. Make sure that *Cylinder* (not cone) is selected, and make sure that *Elliptical Base* is not selected.
2. Set the *Y* value of the *Base* Position to –45, the *Major R* of the Base to 8, the *X* value of the Base
3. *Rotation* to 90, and the *Length* to 10, as in the figure below.
4. Click *Insert* to create the cylinder.
5. Select the spherical shell and add the cylinder with Shift- or Ctrl-click. Select **Edit|Boolean|Subtract** or use the **Boolean Subtract** button to create the circular exit port.

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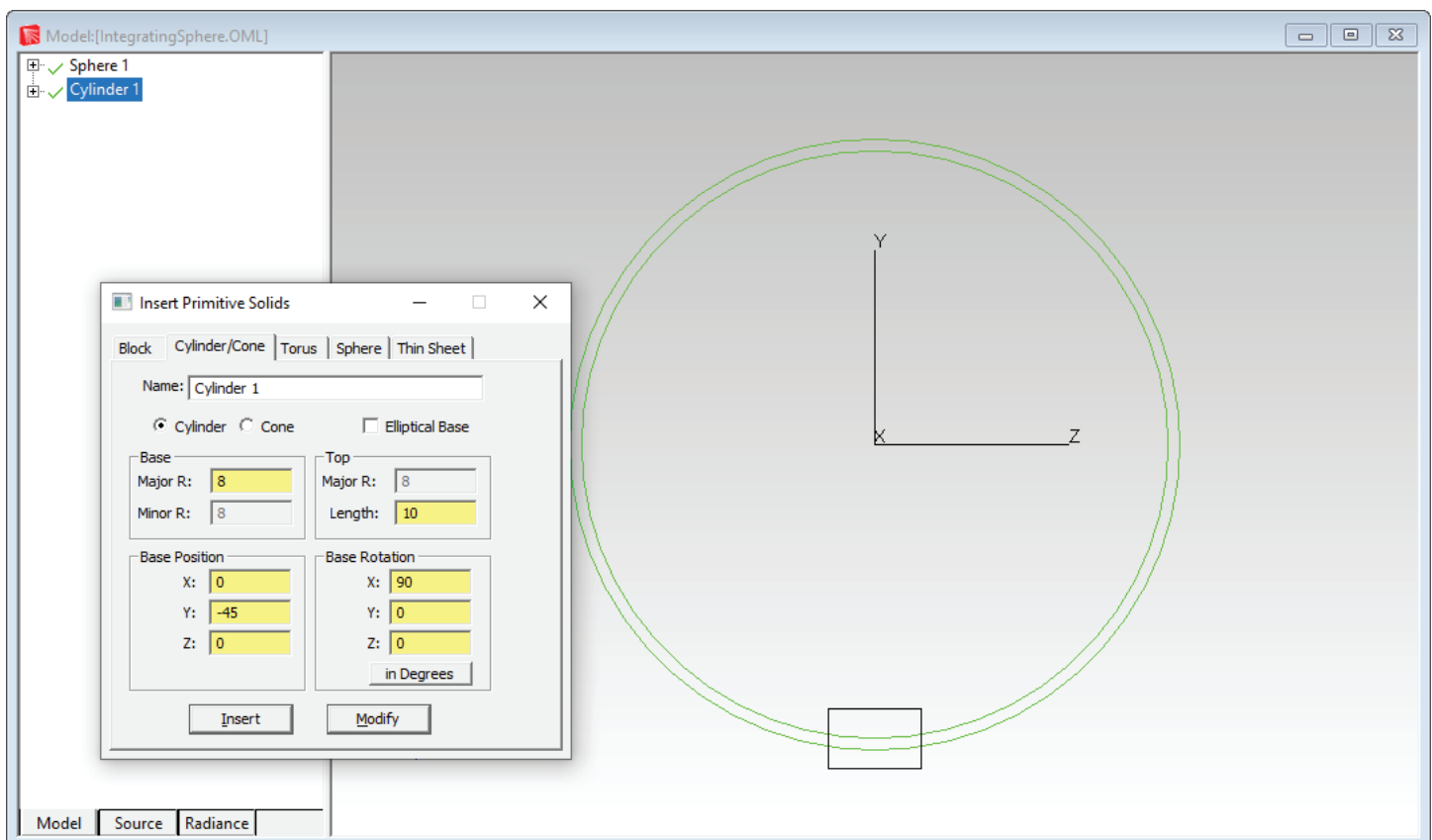
Naming Objects and Surfaces

Use System Tree to add descriptive names to objects and surfaces.

1. In the system tree there is now only one object. Rename this object to Integrating Sphere. To rename an object, first click on the name, and click a second time to enter editing mode. You can also press F2 to enter editing mode. Type in a new name and press Enter. 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 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 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.

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 surfaces to Outer Edge, Detector Surface, and Bottom Surface.
6. Click the **Zoom All** button on the toolbar to rescale the objects in the model window.
7. Rename the object and surfaces as shown.
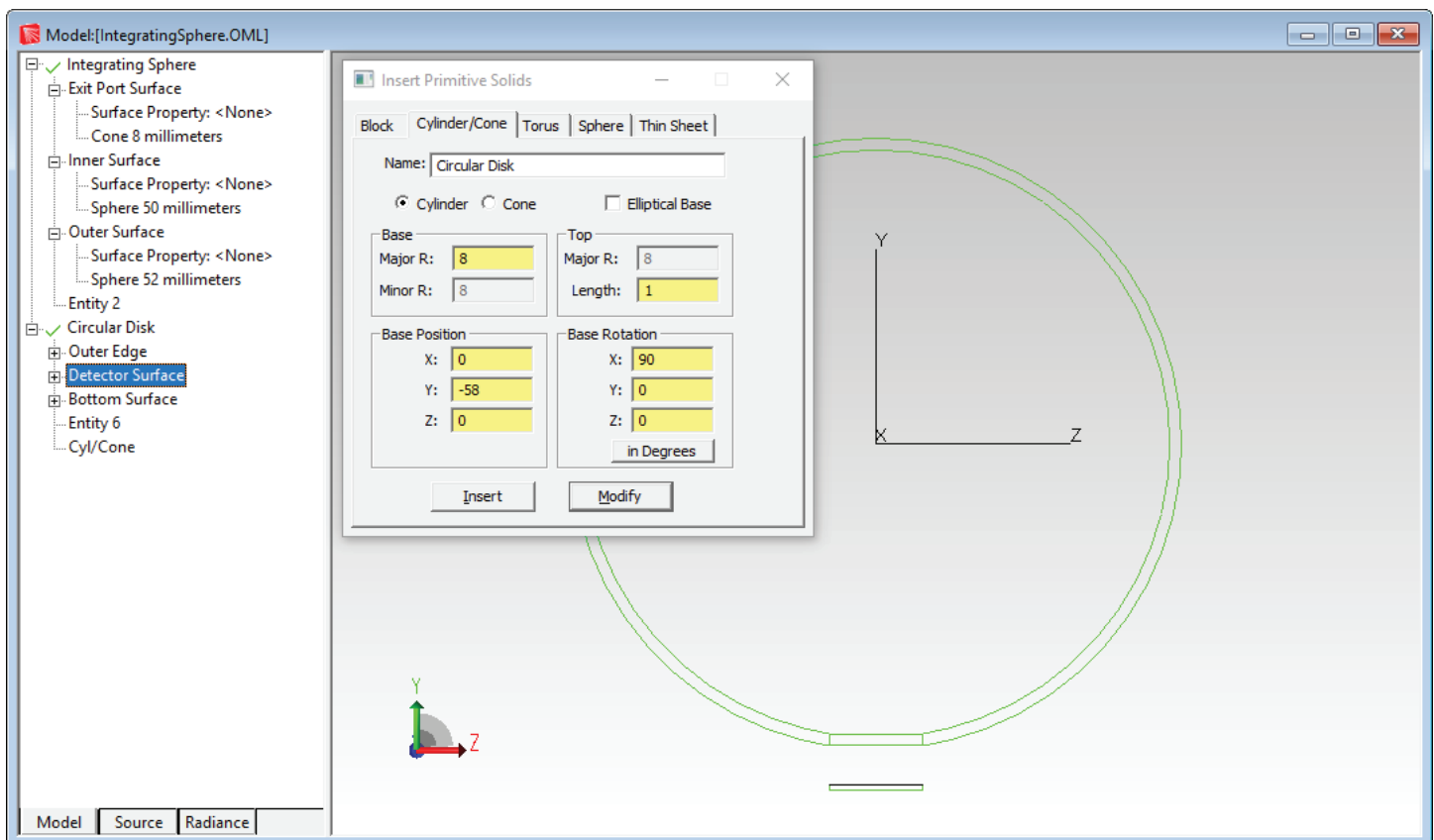
Adding a Surface Property to the Database

TracePro's Surface Property Editor is used to add new surface properties to the database or modify 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 ensure conservation of energy. You will use the Solve for command to compute the BRDF A coeffcient. To define the new surface property:

1. Select **Define|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 *OK*. This will return you to the Surface Property Editor dialog box with default values in the cells.
3. Click the *Absorptance* cell and enter 0.01.
4. From the *Solve for* drop-down list click *BRDF* to calculate the correct value for BRDF A (=.346639466054148) 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.db database file and return to the model window.
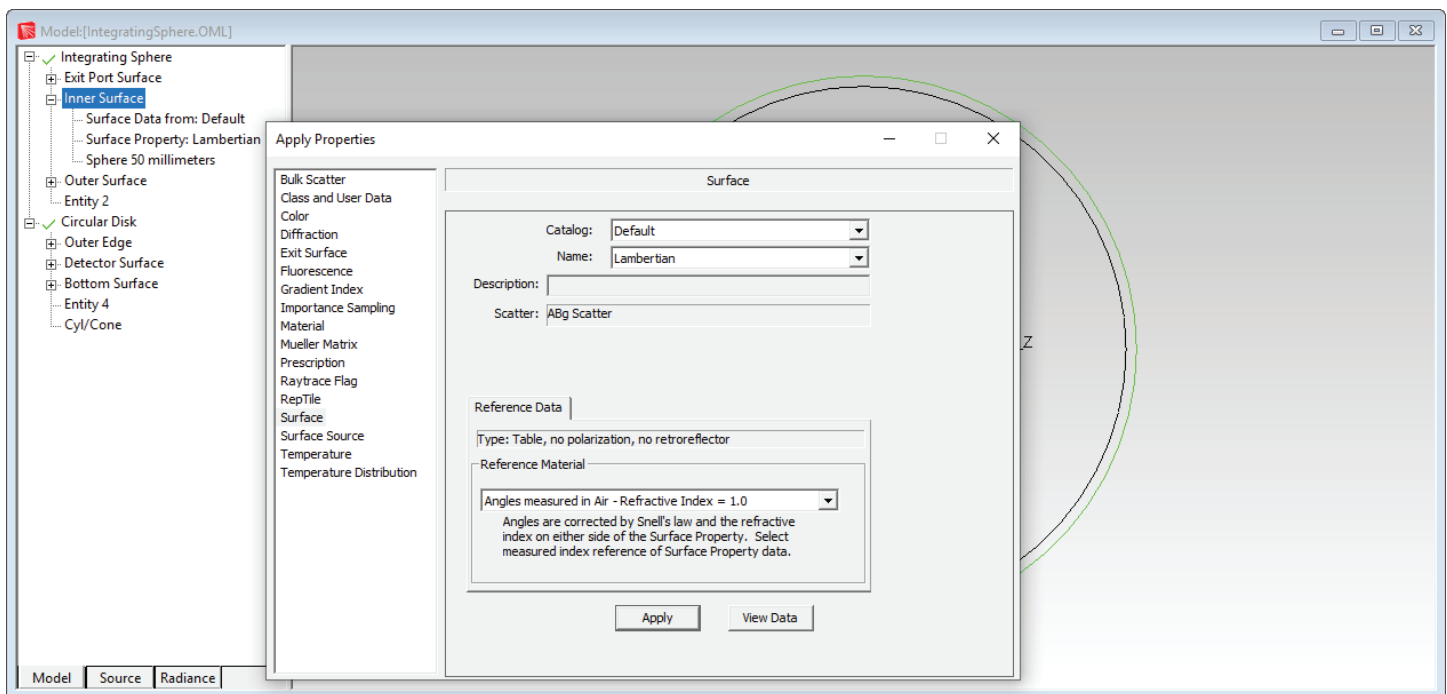

Note: The Lambertian surface property values have only been defined for a single angle of incidence. TracePro will use these values for all angles unless additional angles are defined, in which case TracePro will use linear interpolation to calculate data for intermediate angles.

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Assigning the New Surface Property to the Integrating Sphere

The next step is to assign the Lambertian surface property to the inside of the integrating sphere, as follows:

1. Select the inner surface of the integrating sphere by clicking its name in the system tree.
2. From the *Define* menu select *Apply Properties*.
3. Click the *Surface* tab.
4. From the Name drop-down list select *Lambertian*.
5. Click the *Apply* button.
6. Check in the system tree that the Inner Surface of the Integrating Sphere was assigned the Lambertian surface property.
7. Close the Apply Properties dialog box.

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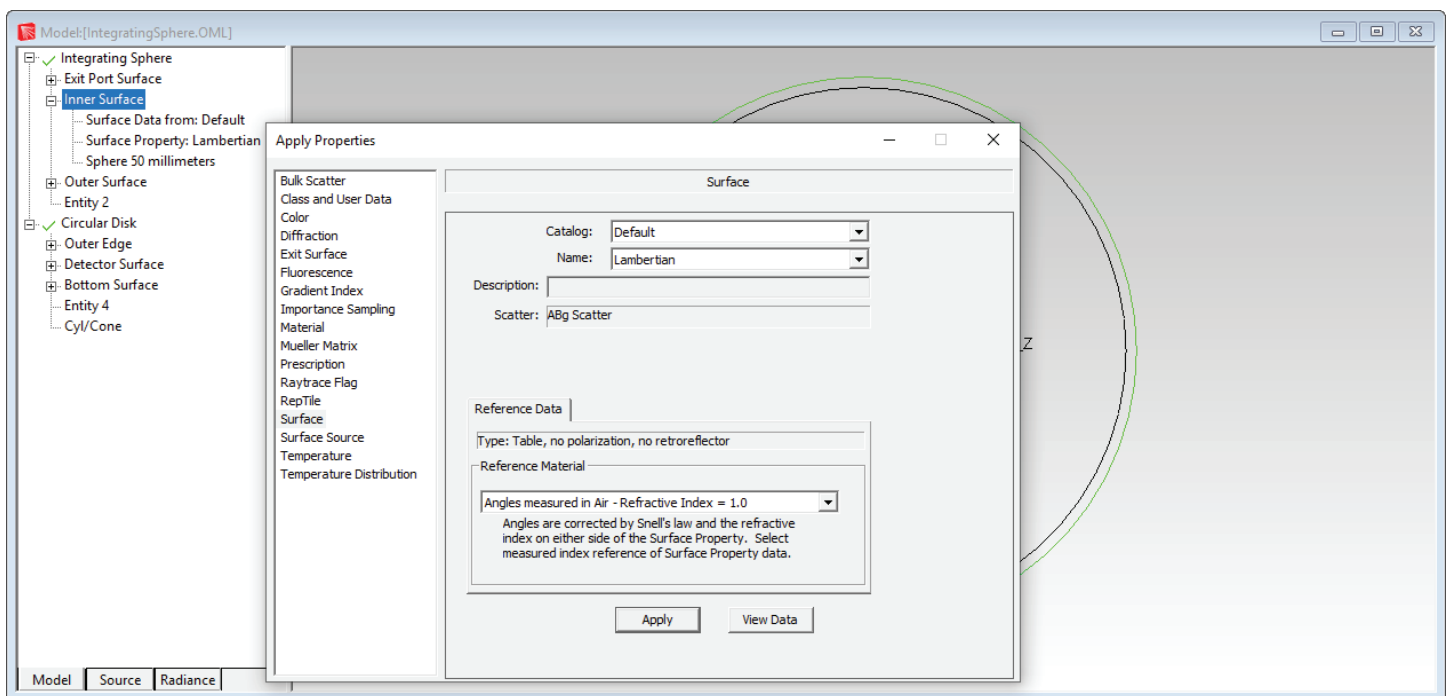
Setting Raytrace Thresholds

efore tracing any rays, you must set 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 set this threshold to 0.0005.

1. Select **Raytrace|Raytrace Options**.
2. Select 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.

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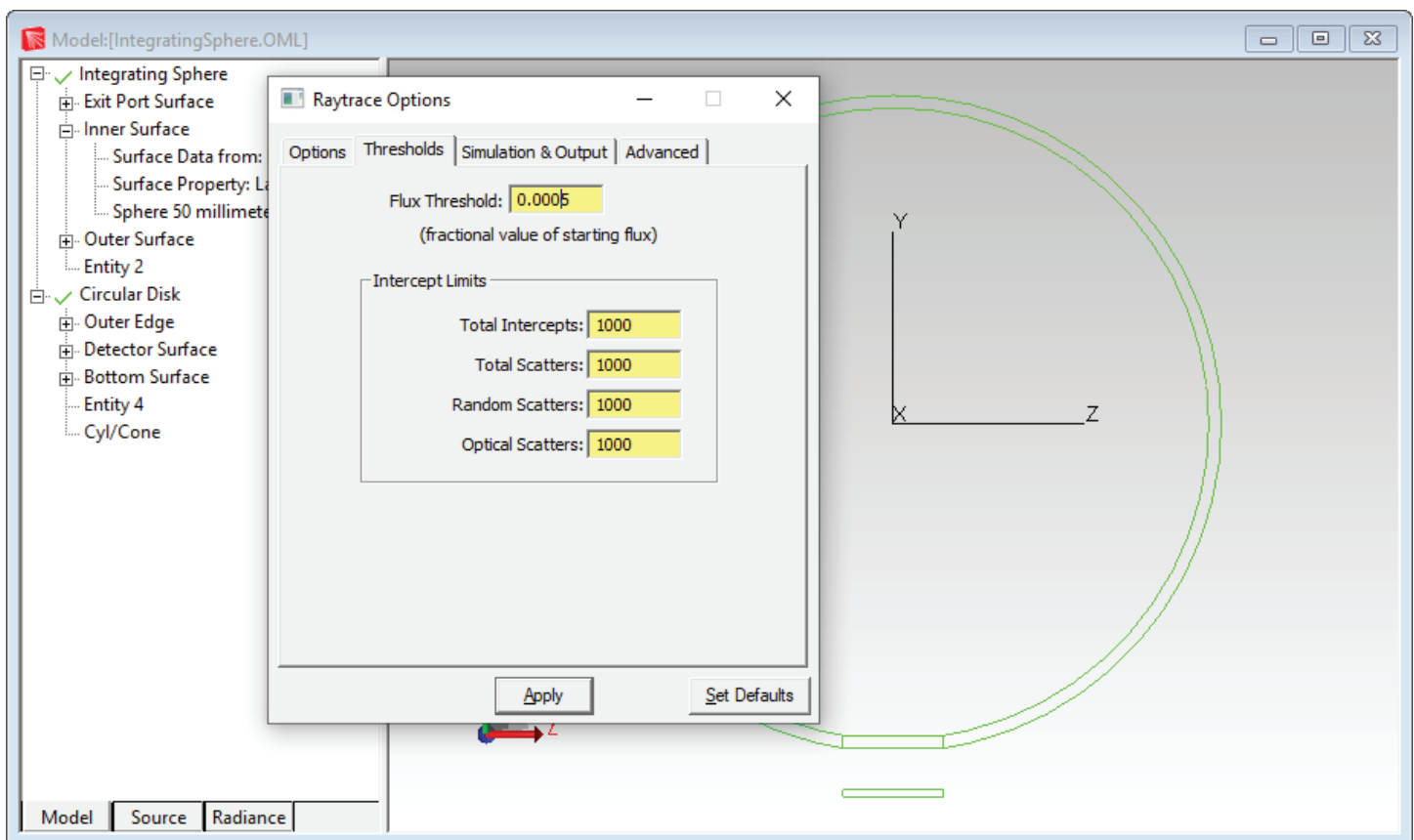
Tracing Rays

In this example you will trace rays from a circular Grid Source. 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. To set up the grid source, first click on the Source Tab at the bottom of the System Tree.
2. Click on the Red X in front of the Grid Source 1 under the Grid Source definitions. This will make Grid Source 1 active.
3. Double-click on Grid Source 1 to open the Grid Source dialog box.
4. Set the *Grid Boundary* to *Annular*, enter 5 for the *Outer radius*, and set the *Inner radius* to 0.
5. For the *Origin* change the *Z* value to 44, leaving the *X* and *Y* components equal to 0.
6. Set the *Normal Vector Z* component to -1, and leave the *X* component set to 0.
7. Set the *Up* vector *X, Y, and Z* components to 0, 1, and 0, respectively.
8. The *Grid Source* dialog box should now appear as shown below.
9. Click the *Modify* button, and then close the Grid Source dialog box.
10. Click the **Trace Rays** icon or select **Raytrace|Trace Rays**. A dialog box will appear asking you to choose between *Analysis Mode or Simulation Mode* raytrace. Choose *Analysis Mode* and click *OK*.
11. First TracePro will audit the model, then the ray-trace will begin. A total of 19 rays will be traced from the Grid Source.
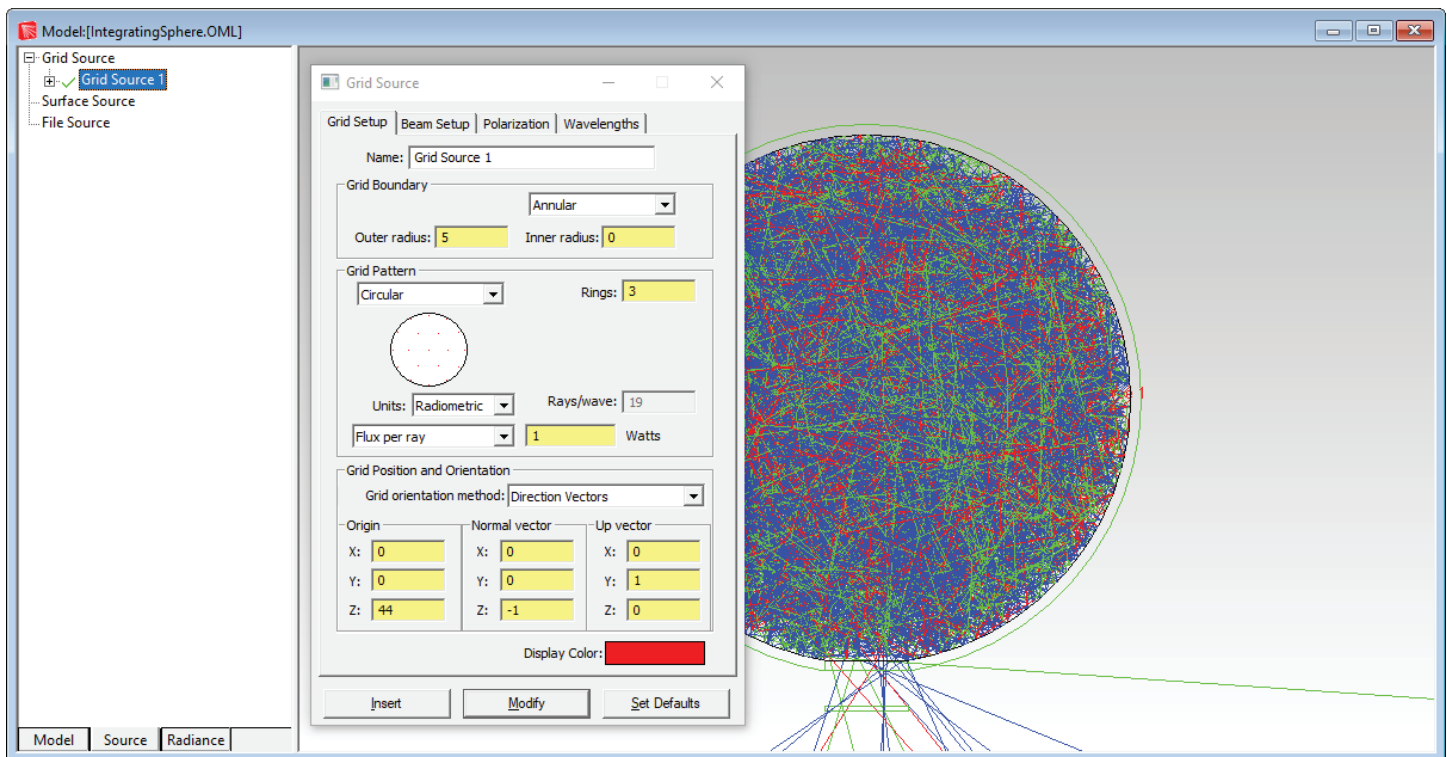
The figure shows the *Grid Source* dialog box and the model window after the Grid Raytrace has finished. Note how the interior of the integrating sphere is filled with rays, with a few rays escaping through the exit port.

Setting the Irradiance Map Options

Create an irradiance map to view the flux incident on the detector surface:

1. Select **Analysis|Irradiance/Illuminance Options**.
2. Select *Incident* in the *Rays to Plot* drop-down list.
3. Select *Grayscale on Black* from the *Color Map* drop-down list.
4. Click the *Automatically calculate Normal and Up Vectors* box.
5. The *Irradiance/Illuminance Map Options* dialog box should match the figure below.
6. Click *Apply* and move the Irradiance/Illuminance Map Options dialog box out of the way.

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. Select the Detector Surface in the object Circular Disk.
2. Select **Analysis|Irradiance/Illuminance Maps** to create the irradiance map. It is shown in the figure below.
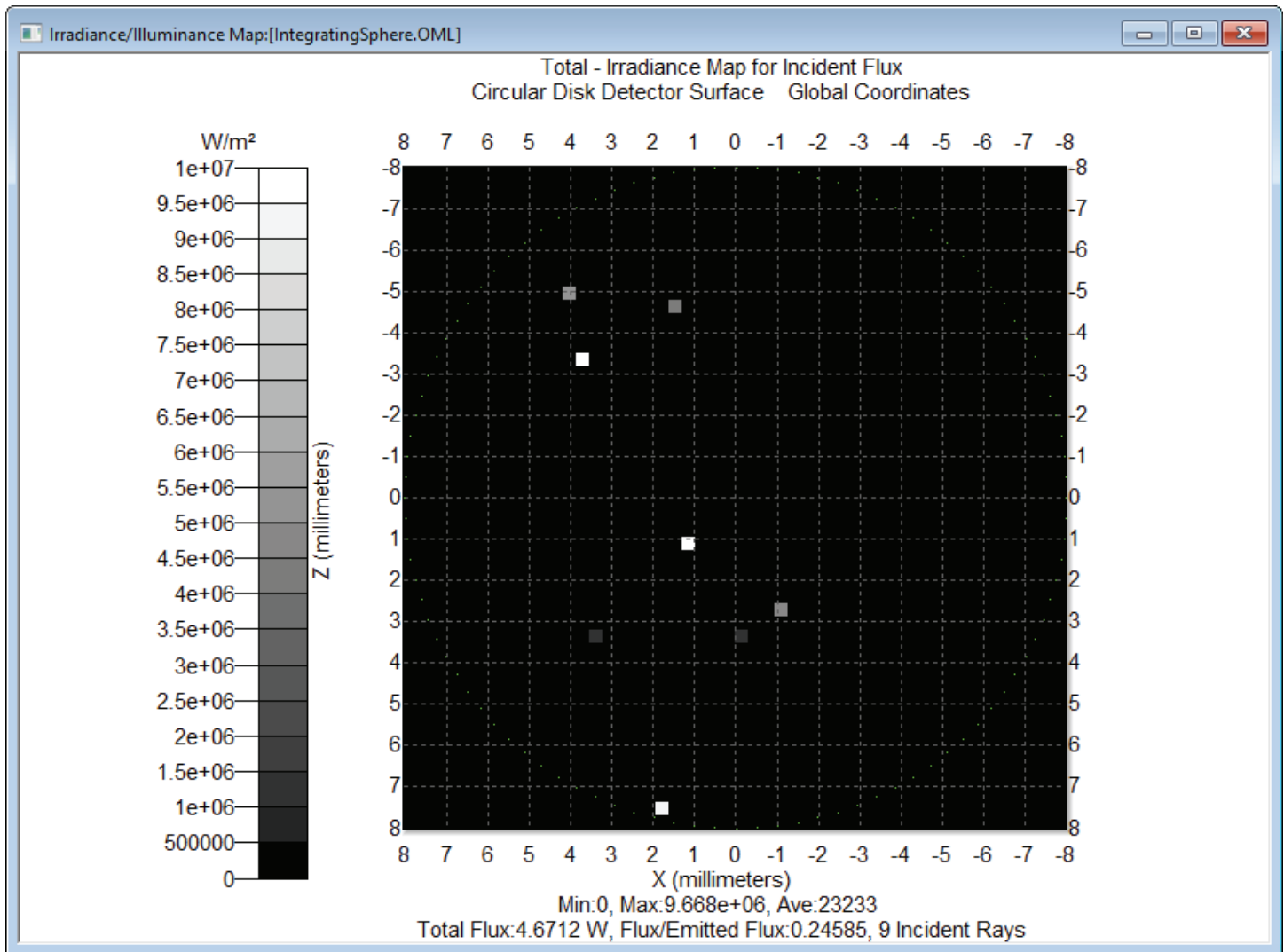
To view these results in false color:

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.

Viewing the Incident Ray Table

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

1. Close the **Irradiance Map** and go back to the model.
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**.

The following figure shows a portion of the table that should be obtained. Note that 6 rays are listed, corresponding to the 6 rays shown in the **Irradiance/Illuminance Map**.

Incident Ray Table:[IntegratingSphere.OML]

Circular Disk Detector Surface

Send to Analysis Toolkit

Ray Number	Wavelength	Source	Start Ray	Ray Node	Type	History	Flux	X Pos.	Y Pos.	Z Pos.	X Vec.	Y Vec.	Z Vec.
1	0.5461	Grid Source 1	2	3	RandRefl		0.99	1.26966	-58	1.09721	0.0452869	-0.749896	0.660003
2	0.5461	Grid Source 1	3	196	RandRefl		0.142307	3.27004	-58	3.25303	0.728288	-0.680639	0.0795448
3	0.5461	Grid Source 1	8	366	RandRefl		0.0257757	3.01548	-58	-5.70194	0.0924764	-0.638786	-0.763807
4	0.5461	Grid Source 1	9	9	RandRefl		0.932065	1.798	-58	7.59229	0.10596	-0.77752	0.619868
5	0.5461	Grid Source 1	10	78	RandRefl		0.465881	-0.981269	-58	2.85931	0.110805	-0.893323	0.435542
6	0.5461	Grid Source 1	11	195	RandRefl		0.143745	-0.104003	-58	3.23084	0.452767	-0.891629	-0.000448358
7	0.5461	Grid Source 1	12	4	RandRefl		0.9801	3.52858	-58	-3.40237	0.35115	-0.792835	-0.498102
8	0.5461	Grid Source 1	16	84	RandRefl		0.438618	1.3313	-58	-4.67883	-0.238785	-0.939665	0.244971
9	0.5461	Grid Source 1	19	61	RandRefl		0.552683	3.93247	-58	-4.89541	-0.102907	-0.953146	-0.284469

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. Go back to the model.
2. Select the **Inner Surface of the Integrating Sphere**.
3. From the **Define** menu select **Apply Properties**.
4. Click the **Importance Sampling Tab** in the **Apply Properties** dialog box.
5. For **Target 1** change the **Target Center Y value to -49.355851**, change the **Normal Vector to (0,1,0), the Up Vector to (0,0,1),** and change the **Outer Radius value to 8** as shown.
6. Click **Apply**.
7. Check the system tree to verify that an **Importance Target** has been defined on the **Inner Surface of the Integrating Sphere**.
8. Close the **Apply Properties** dialog box.

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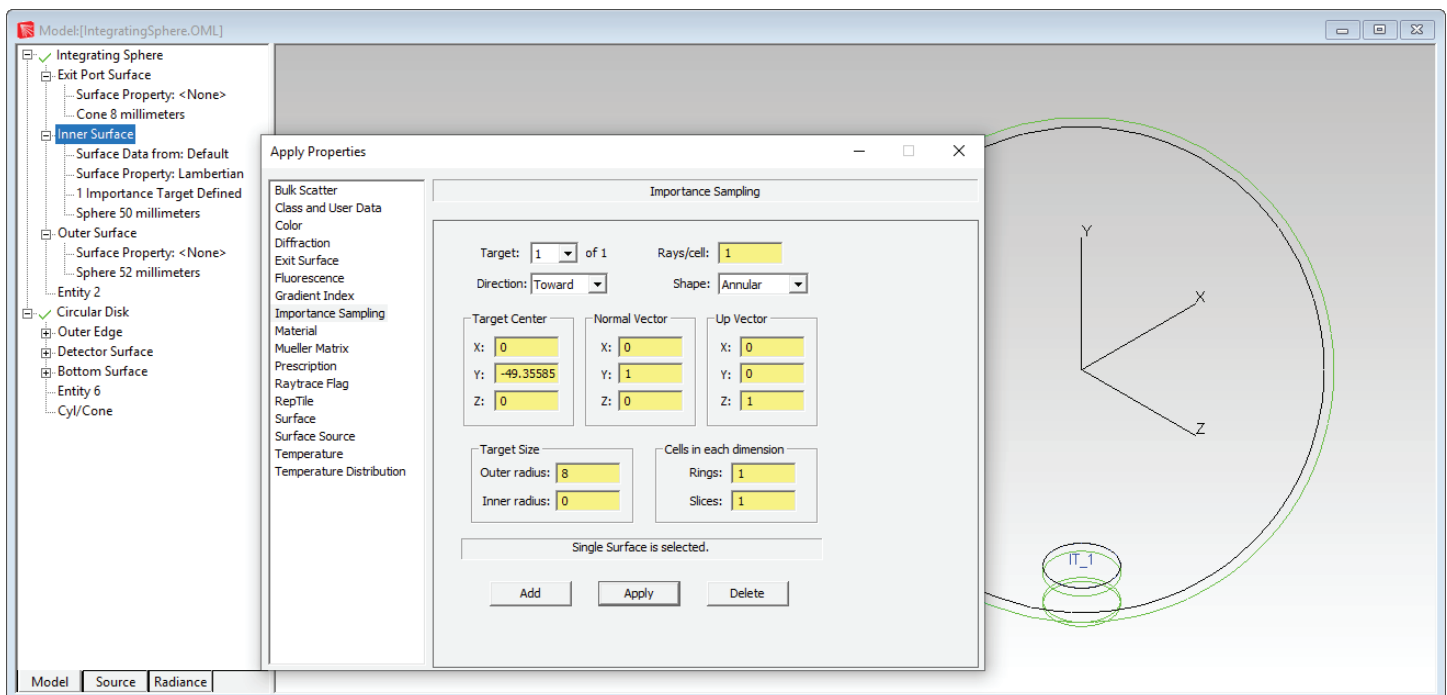
Raytrace with an Importance Target

1. Select **Raytrace | Trace Rays** to start the raytrace.

The figure shows the grid raytrace with importance sampling turned on.
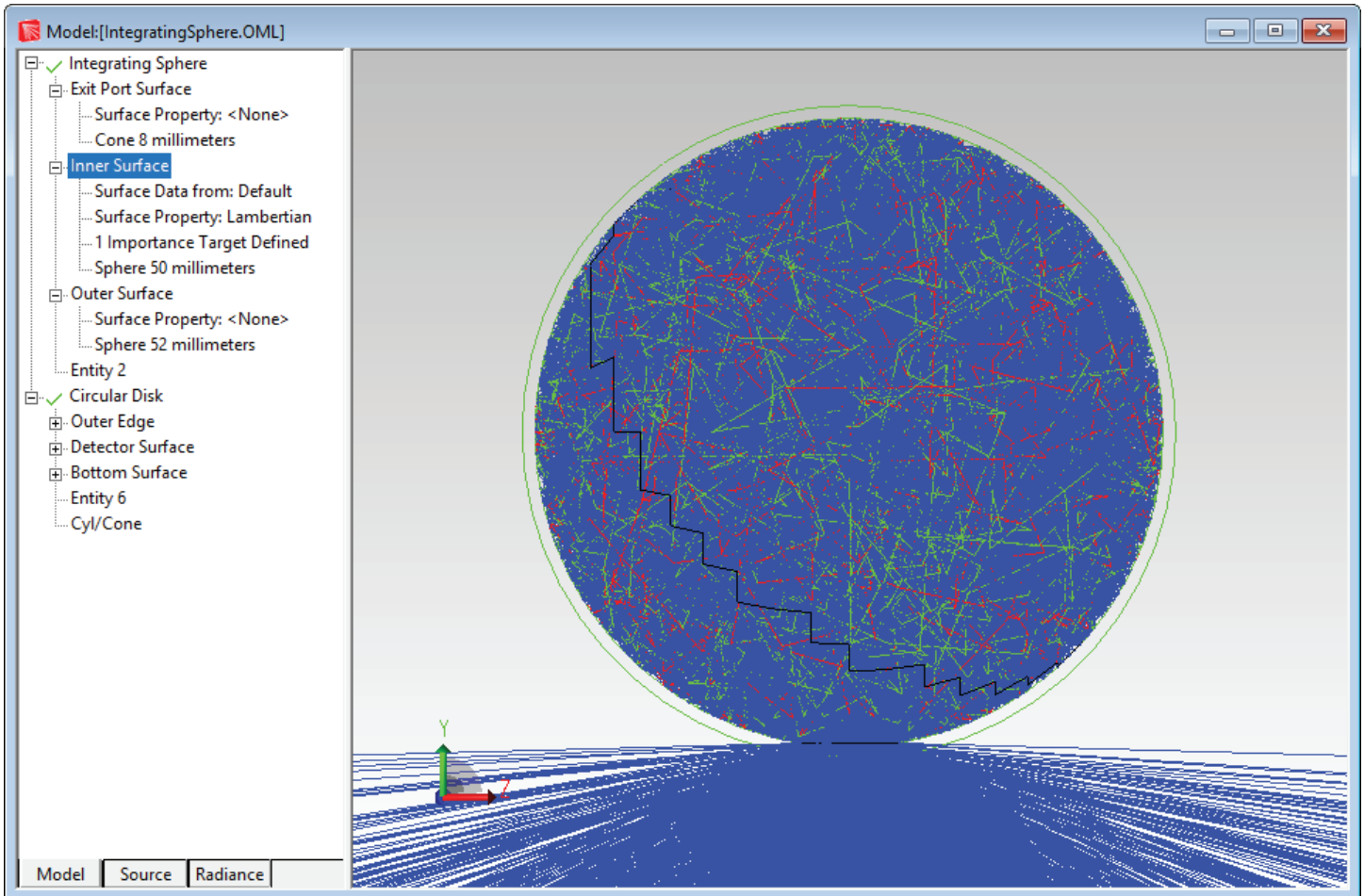
Irradiance Map with Importance Sampling

Now you can view the updated irradiance map.

1. Click to select the Detector Surface in the system tree.
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.
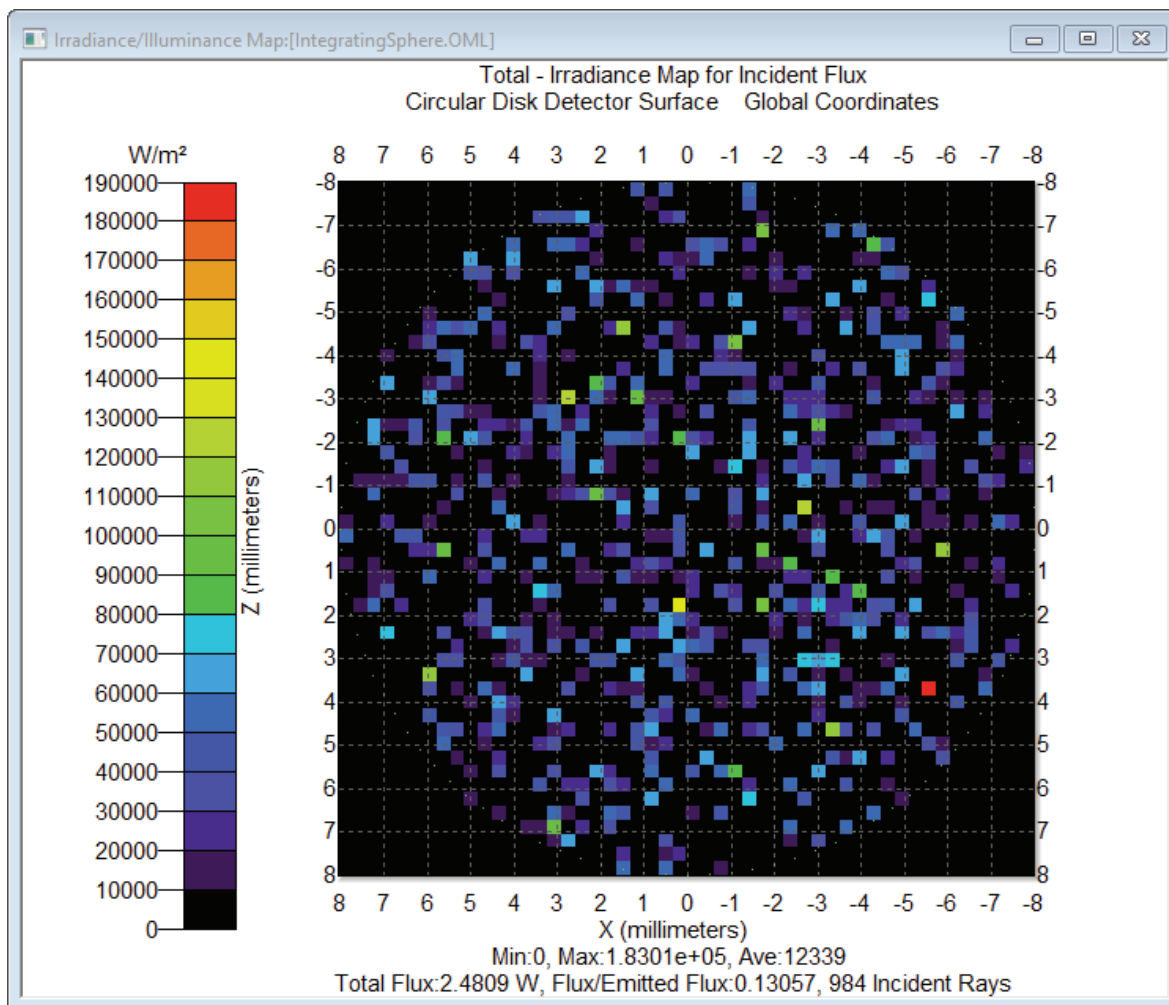
Note: You can apply smoothing or increase the number of rays to improve the ray sampling in the plot.

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** or use the tile vertical button.
2. You can Resize the different windows to your liking.