

# Nomenclature and use of TracePro<sup>®</sup> asymmetric table BSDF

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## Introduction

By way of explaining the use of the asymmetric table BSDF feature in TracePro, we will study in detail a specific example of a surface property that uses asymmetric table BSDF. This property has data at angles of incidence of 0, 5, 25, and 45.1 degrees. The table BSDF has equally-spaced beta values of 0.0, 0.01, 0.02, ... 2.0, and the equally-spaced azimuth angle values of 0, 10, 20, ... 350 degrees. Thus there are 7236 entries for each angle of incidence, for a total of 28,944 entries.

We can look at the BRDF of this property graphically; all the BTDF values are zero. By importing the property into a spreadsheet program such as Microsoft Excel, choosing one angle of incidence, and reformatting the data into a rectangular table, we can make a surface plot of the BRDF. Figure 1 shows an Excel surface plot for the 45.1 degree angle-of-incidence data set, with beta values along the long axis and azimuth angles along the short axis. At small values of beta, we can see two ridges in the BRDF, one at azimuth 90 degrees, the other at azimuth 180 degrees. These ridges correspond to an elongated near-specular spot, with the elongation occurring in the 90 and 270 degree directions. At large values of beta, the BRDF is zero outside an approximately circular region. This circular region is evidently decentered along the 180 degree azimuth direction, resulting in zero values for small beta values along the 0 (360) azimuth direction. It is evident from examining the symmetry of the BRDF values that in the measurement coordinate system, the plane of incidence was along the 0 – 180 degree axis, with the incident beam in the 180 direction and the specular beam in the 0 (360) direction.

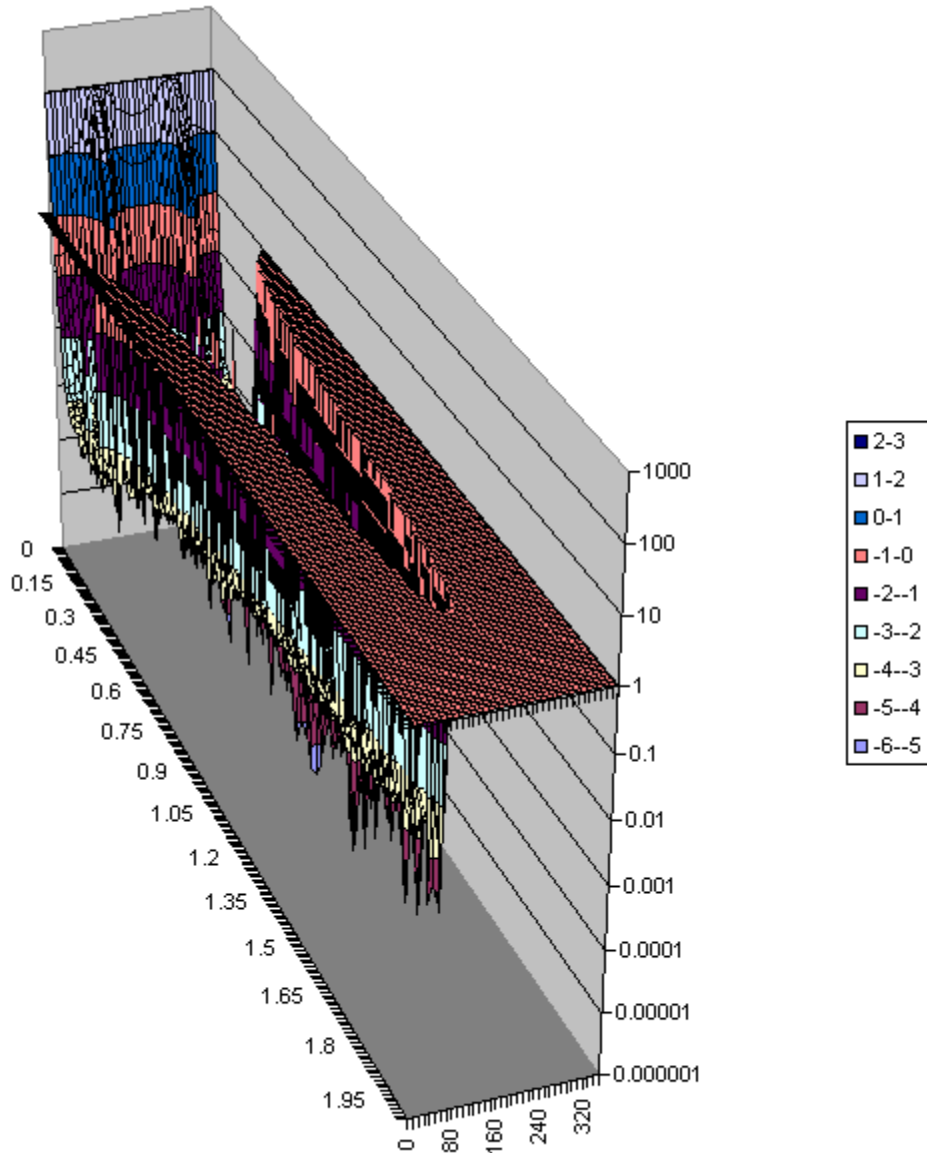


Figure 1. Surface plot of  $\log(\text{BRDF})$  versus beta and azimuth angle, plotted as a surface plot in Microsoft Excel. Due to a bug in Excel when displaying a logarithmic surface plot with zero values, all zero values are plotted as having the 1.0. This bug helps us, in this case, to see the zero values more clearly.

## Asymmetric table BSDF in TracePro

When you apply this surface property to a surface in TracePro, you can select whether to use a fixed axis for referencing the BSDF, or use an axis that depends on the direction of incidence. In the sections that follow we will see what behavior each of these choices produces.

Whether you choose a fixed reference axis or one that varies with direction of incidence, TracePro uses a local coordinate system to superimpose the BSDF on the surface. This local

coordinate system has a z axis that is normal to the surface at the point at which the incident ray strikes the surface. The local x and y axes lie in the surface tangent plane. The tangent plane is a plane that is tangent to the surface at the intersection point of the incident ray with the surface. In the property, the 0 degree azimuth data is along the local x axis, and the 90 degree azimuth data is along the local y axis. On the surface, the orientation of the local x and y axes depends on the choice of using the fixed reference axis or not.

- 1) When the fixed reference axis is chosen by checking the checkbox shown in Figure 3 (this is the default behavior in TracePro), the local x axis lies along the axis entered in the data box below. If the axis does not lie in the tangent plane for a particular incident ray, it will be projected onto the tangent plane along the surface normal.
- 2) When the fixed reference axis is not chosen, then the local x axis is calculated. *The calculated x axis is perpendicular to the plane of incidence.* It is the vector cross product of the direction of the incident ray with the surface normal. The azimuth angle zero data lies along this axis, and the 90 degree azimuth data lies along the local y axis. The surface normal points toward the reflection side of the surface for BRDF, and toward the transmission side for BTDF.

### ***Fixed reference axis for BSDF***

Figure 2 shows one scenario for using the surface property described above. The fixed reference option is used, and reference axis direction is (-1,0,0) as shown in Figure 3. This means that the local x axis is along the -x global axis, and the local y axis is along the z global axis (0,0,1). The surface normal is along the global y axis or (0,1,0).

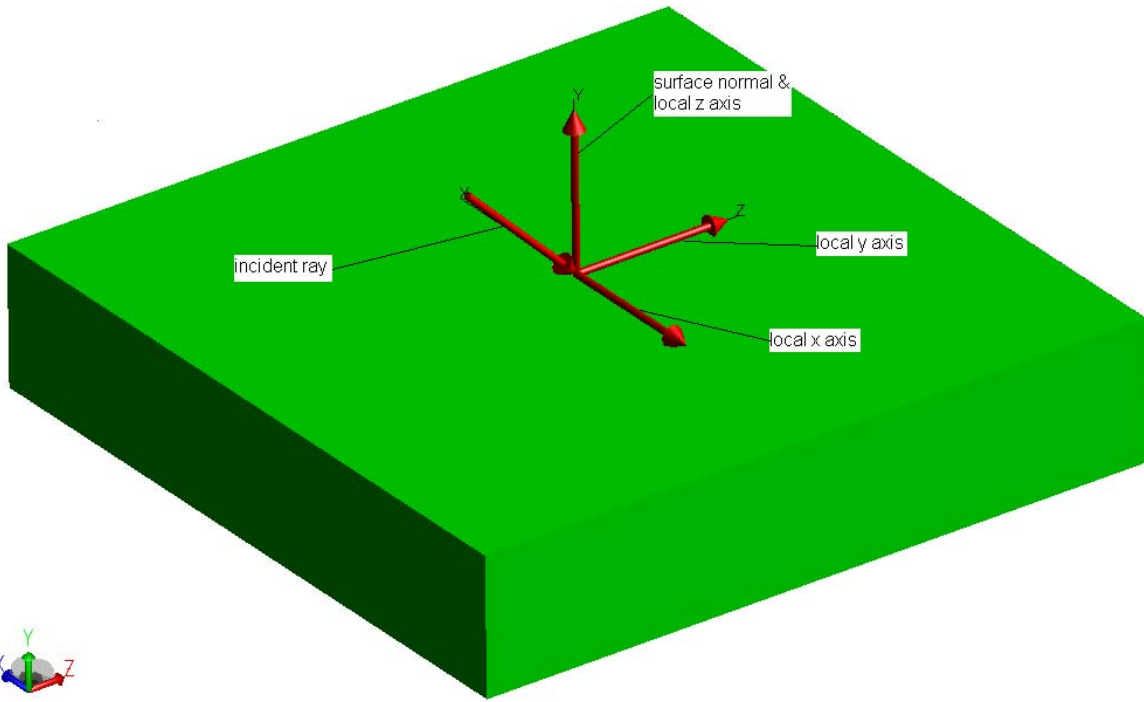
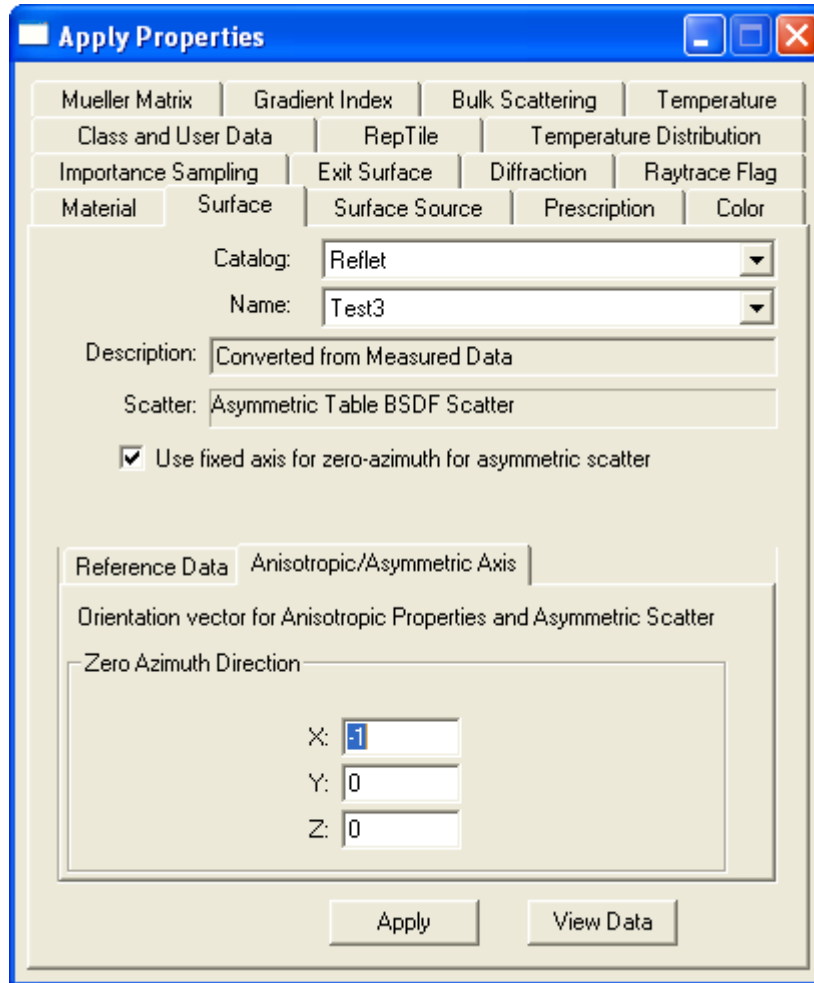
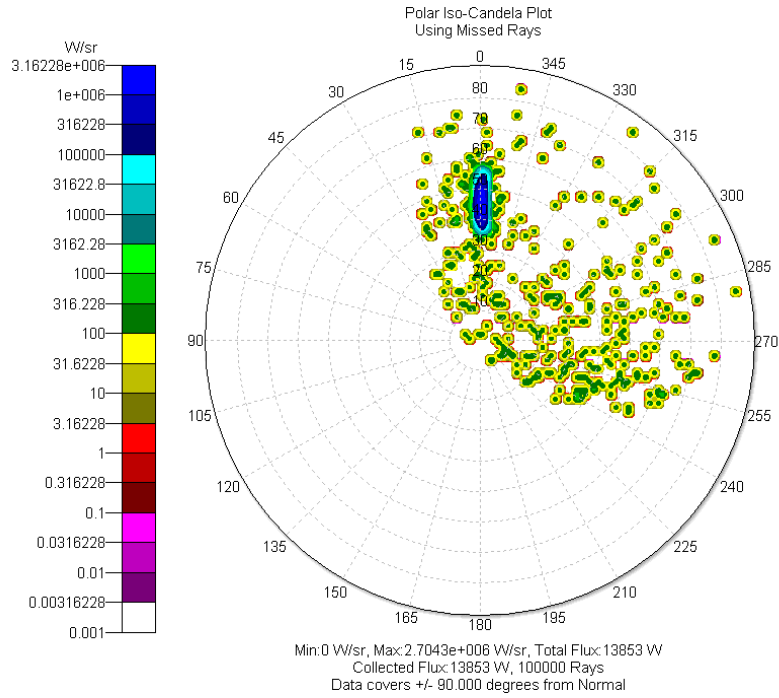


Figure 2. Example of fixed reference axis along the  $(-1,0,0)$  direction and surface normal along the  $(0,1,0)$  direction.



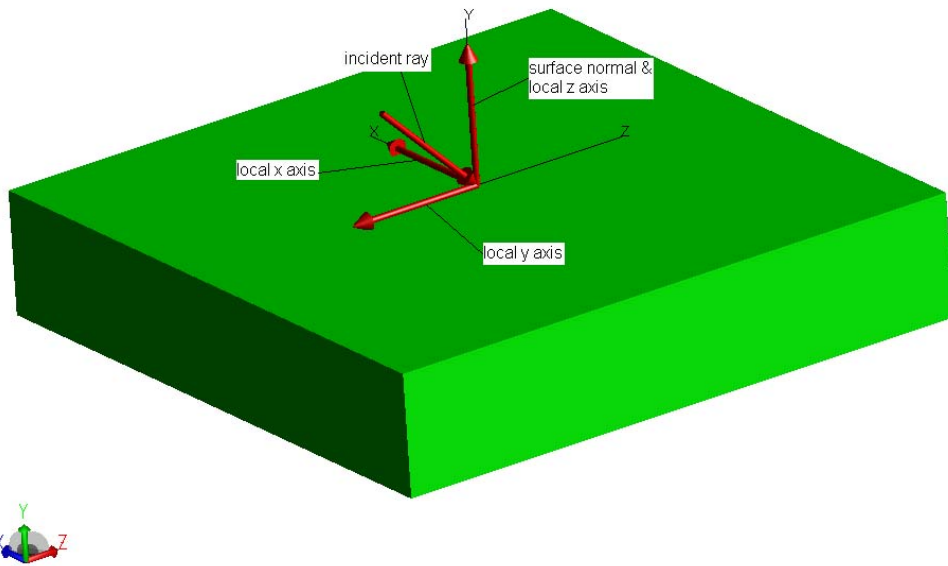
**Figure 3. Apply Properties dialog box, Surface tab, showing fixed reference axis along (-1,0,0).**

A ray trace with 100000 rays produces the intensity plot shown in Figure 4. The Normal Vector for this intensity plot is (0,1,0) and the Up Vector is (0,0,1). This orientation of the plot is illustrated by placing your eye at the origin and looking out along the global y axis, with the top of your head pointed along the global z axis, and picturing the intensity projected on a hemisphere in front of you. With the zero azimuth direction (or local x axis) of the property application along the (-1,0,0) global axis, the 90 – 270 elongation of the near-specular is along the local +/- y axis, or along the global z axis, or in the vertical direction as you can see in Figure 4. The truncated part occurs in the 0 (360) azimuth direction, which is along the -x axis. From the point of view of intensity plot, the -x axis points to the left, and the intensity is therefore truncated on the left as you can see in Figure 4.



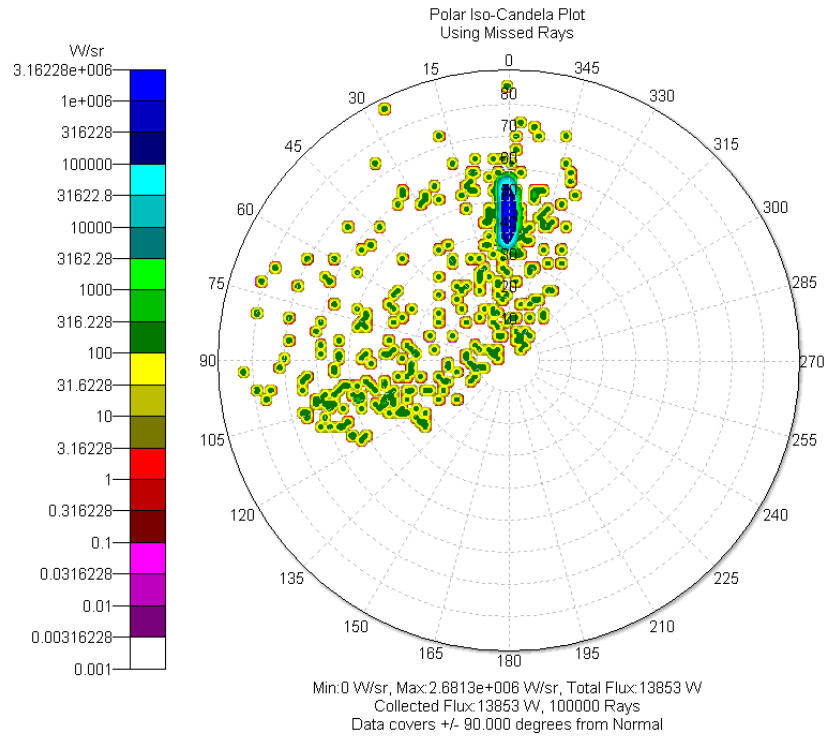
**Figure 4. Intensity plot for fixed axis along  $(-1,0,0)$ .**

Figure 5 shows another scenario for using a fixed reference axis for the BSDF. In this case the reference axis is along  $(1,0,0)$ , the global x axis, so the local and global x axes are colinear. The local z axis is the surface normal, which is along the global y axis as before.



**Figure 5. Fixed reference axis with local x axis along the global x axis.**

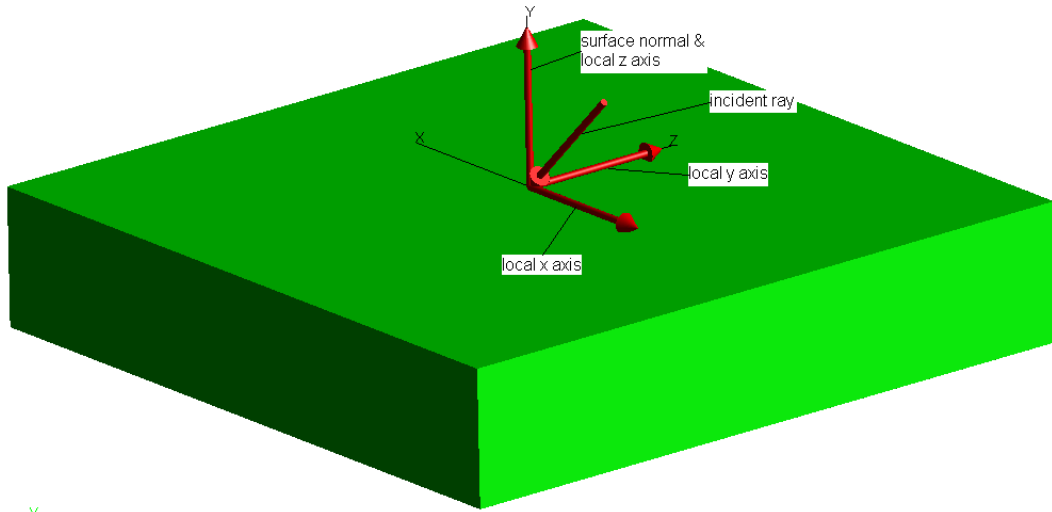
This orientation of the fixed axis, with light incident in the y-z plane as before, produces an intensity plot as shown in Figure 6. The  $|\beta-\beta_0| = 0$  direction is the same as before because the ray is incident in the same direction, but now the pattern is truncated on the right instead of the left. The whole pattern has rotated by 180 degrees around the specular direction, because we have rotated the fixed axis by 180 degrees.



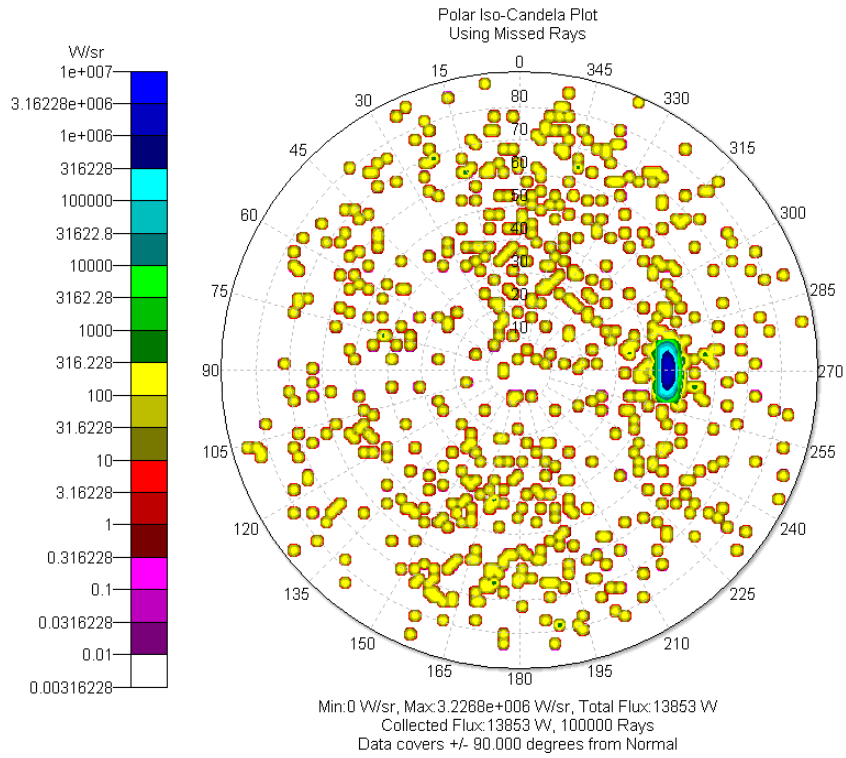
**Figure 6. Intensity pattern with fixed reference axis along (1,0,0) and ray incident in the y-z plane.**

For our final fixed-axis example, we change the fixed axis back to be the same as for the first example, or along (-1,0,0), but now the light will be incident along the -x axis, as shown in Figure 7. This produces the intensity pattern shown in Figure 8. We see that the orientation of the scattered pattern is the same as in Figure 8, but now the specular direction has moved because the incident direction has moved.

We can summarize the behavior of the fixed-reference-axis model this way: the scatter pattern stays in a fixed orientation but the center of the pattern (the specular direction) moves as the incident direction changes.



**Figure 7. Fixed reference axis along the  $(-1,0,0)$  direction with light incident along the x axis.**

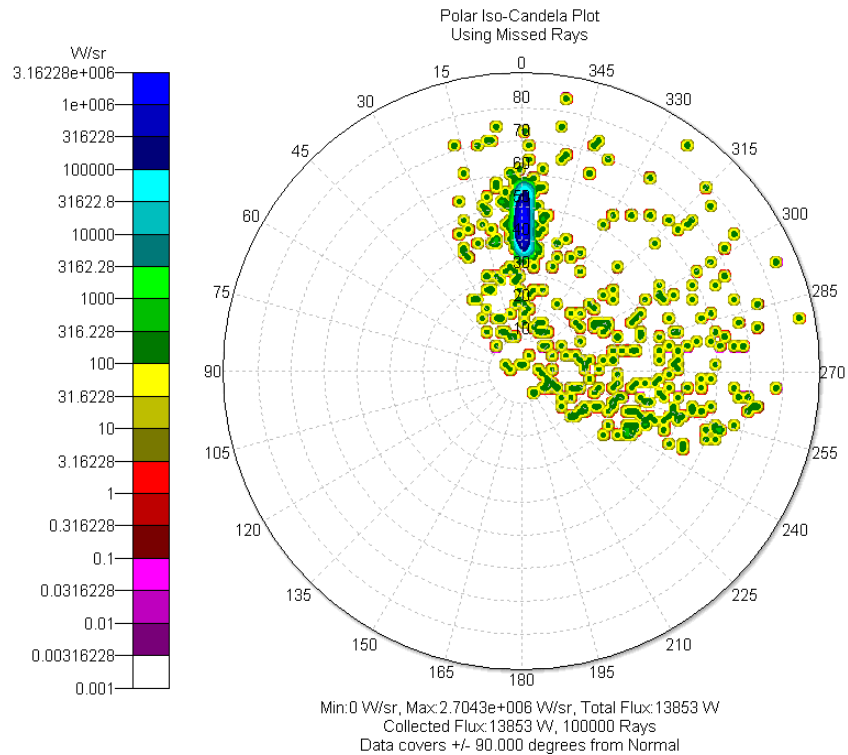


**Figure 8. Intensity pattern for fixed reference axis along  $(-1,0,0)$  and ray incident along  $+x$  direction.**



## Non-fixed reference axis for BSDF

Our first example of non-fixed reference for BSDF axis has light incident in the  $y$ - $z$  plane, the same as our first example for fixed reference axis. Because the cross product of the incident ray with the surface normal is along the  $-x$  axis, the coordinate system is the same as for our first fixed-axis reference example and is shown in Figure 2. The resulting intensity pattern is shown in Figure 9, and we can see that it is the same as Figure 4, as it should be.

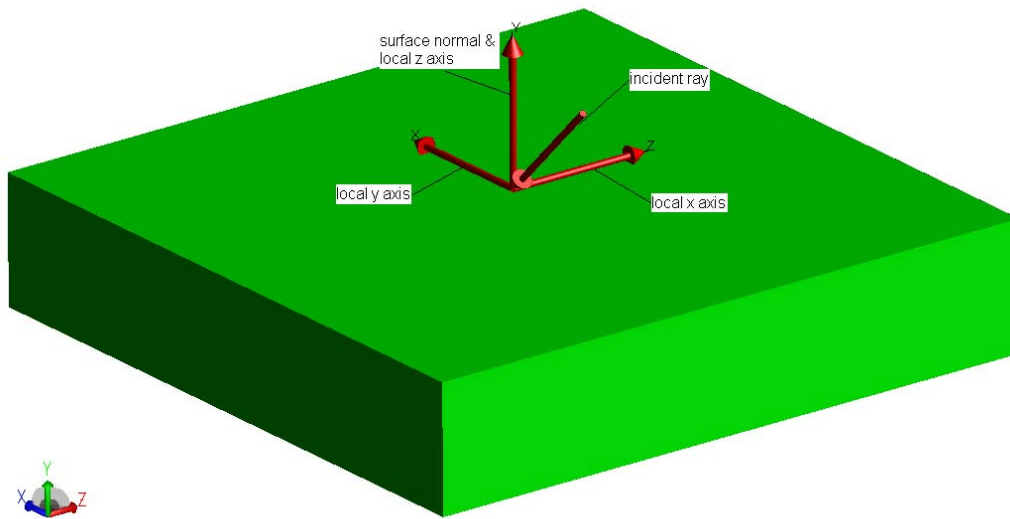


**Figure 9. Intensity pattern for non-fixed reference axis, light incident in the  $y$ - $z$  plane.**

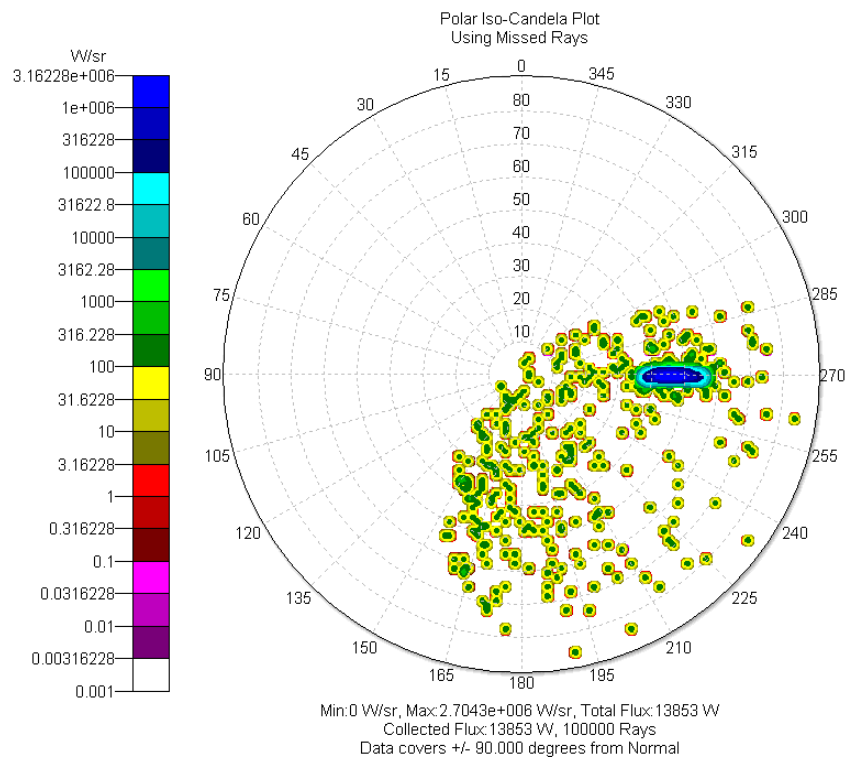
Our second example of non-fixed reference axis has light incident along the  $x$  axis, the same as our third example for fixed reference axis. However, now the local coordinate system changes along with the incident direction, as shown in Figure 10. We know that the BRDF is truncated in the  $0$  ( $360$ ) direction, which is along the local  $x$  axis or global  $z$  axis for this case. Therefore, the intensity map should be truncated along the  $+z$  axis, as shown in Figure 11.

We can summarize the behavior of the non-fixed reference axis case as follows: the intensity pattern rotates along with the plane of incidence.

Note that when a non-fixed reference axis is used, there is a problem for light incident normal to the surface, because the cross product of the incident direction with the surface normal produces zero. Therefore the local  $x$  and  $y$  axes are undefined. TracePro will generate a random direction in the tangent plane for the local  $x$  axis in this case, and construct the local  $y$  axis using the right-hand rule. Therefore, use of the non-fixed reference axis produces a nonsensical result unless the BSDF at zero incidence angle is symmetrical.



**Figure 10. Non-fixed reference axis, with light incident along the +x global axis. The local x axis is along the (0,0,1) direction, and the local y axis is along the (1,0,0) direction.**



**Figure 11. Intensity plot for non-fixed reference axis, with light incident along the +x axis.**