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Title: Differences between the TALLYX and fmesh cell tagging capabilities (U)

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SUBJECT: Differences between the TALLYX and fmesh cell tagging capabilities (U)

Abstract

The TALLYX tally method has been available for use in special versions of MCNP for the past few years while the fmesh tally method has just been implemented in MCNP in the past year. The fmesh tally method will supersede the TALLYX method in new versions of the code. The cell tagging capabilities of the TALLYX and fmesh tally methods in MCNP are compared in x-ray radiography simulations to verify their consistency.

I. Introduction

Contributions of various target components to the transmission image produced in simulated x-ray radiographs can be quantified by using the cell tagging tally capabilities available in MCNP. The TALLYX and fmesh tally methods available in newer versions of MCNP allow the user to separately tally particles that pass out of cells specified in the input cards. This cell tagging capability allows better quantification of backgrounds, cross-talk, and other items of interest in high accuracy quantitative radiography. The TALLYX tally method is a surface tally method that divides a surface into a grid of two-dimensional pixels. The number of particles that cross each pixel is recorded and a two-dimensional image of the target can be determined from the results. The fmesh tally is a volumetric tally that records the total track length of all the particles (number of particles * track length) that pass through a grid of three-dimensional voxels. The recorded particle track lengths for each voxel are divided by the volume of the voxel to give the particle fluence (particles/area) for each voxel. The pixel values from the TALLYX method can be divided by the area of the pixels in order to give a corresponding fluence for the TALLYX results.

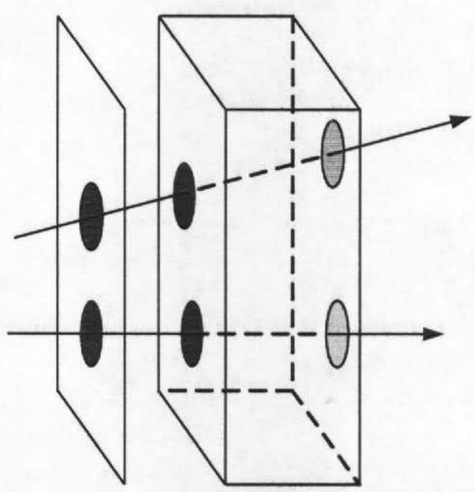

Figure 1- An illustration of two particles crossing the TALLYX surface tally pixel on the left and the fmesh volume tally voxel on the right.

An illustration of how each tally method will tabulate two particles with different trajectories crossing through a pixel and a voxel is shown in Figure 1. The TALLYX surface tally on the left will count both particles equally. The fmesh volume tally on the right will give a larger tally value to the top particle than the bottom particle since the top particle has a longer trajectory through the voxel. The measure of the particle track length in the fmesh tally gives a more realistic measure of each particle's contribution to a grid area since the angular dependence of the particle trajectories is accounted for in the tally. The difference between the two tally methods will depend upon the degree of deviation of the particle trajectories from the normal to the detector surface. Therefore the differences will always be somewhat dependent on the source, target, and surrounding experimental components.

II. Simulations for comparison of the two tally methods

Simulated radiographs were made of a target comprised of six concentric aluminum cylinders with a length of 3 cm and a total diameter of 3cm (Figure 2). The radii for the cylinders were 0.25cm, 0.50cm, 0.75cm, 1.00cm, 1.25cm, 1.50cm. Tagged tallies were made for three of the six different cylinders in the target. The one, four, and six numbered cylinders were tagged so the differences between the two methods would be compared as a function of radial distance from the beam center. Cylinders were used for the targets so the same areal density would exist along the beam axis. The target location along the beam axis in the experiment is shown in Figure 3. The beam travels from right to left. The target is 72.28 cm from the source, 8.5 cm from the collimator, and 0.5 cm in front of the tally surface.

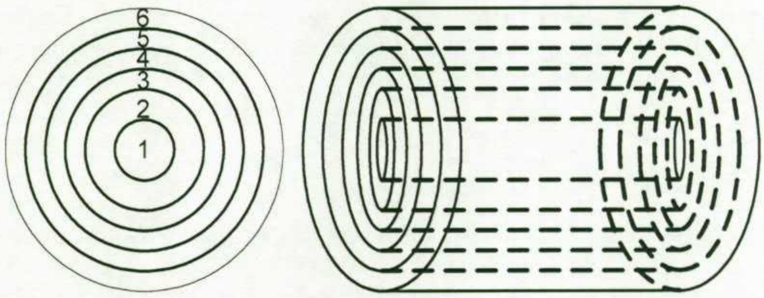

Figure 2 – Front and side views of the cylindrical target used for the cell tagging tally simulations.

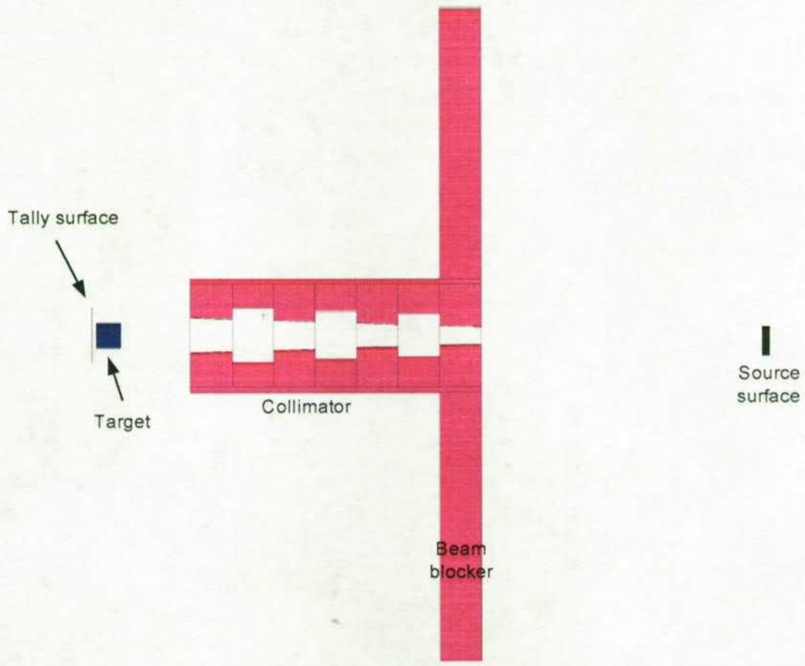

Figure 3- MCNP input geometries for the tagged cell simulated x-ray radiographs.

A model of an actual source with collimation is used in the simulations instead of an ideal beam with trajectories parallel to the beam axis. Use of an ideal source for this study will not provide a useful guideline for comparing the different tally method results for simulations based on actual experiments. The source in these simulations is a histogram representation of the Cygnus source calculation by Menge. The source is 75.78 cm from the tally surface and has a spot size of 1.5mm with a 3.1 degree beam spread. The source is positioned 28.22 cm in front of the collimator so the cylindrical area of the beam is larger than the rectilinear area of the front opening of the collimator. The beam is constrained by a collimator with a horizontal angular spread of 2.38 degrees and a vertical angular spread of 3.53 degrees. The collimator dimensions were taken from recent experiments using the Cygnus source. The beam blocker did not exist in the radiography experiments but was added to the simulations to insure no stray scattering of photons from the source could reach the tally surface.

The detector grid at the tally surface for the simulations is 7cm by 7cm with 350 pixels per side. The length per side of a pixel (or voxel front surface) is 0.2mm. The grid dimensions were made large enough to insure that the collimated edge of the beam could be clearly seen in the transmission image. The detector grid is 0.5 cm behind the target. The grid for the TALLYX tally is defined on a cell comprised of air. The TALLYX tally requires the tally surface to be part of a cell defined in the input and must be positioned along the Cartesian axes. The fmesh tally does not require the tally volume to be part of a cell and can be positioned anywhere. In these simulations the rear surface of the fmesh grid is on the same surface as the TALLYX tally surface and extends in front of it 0.01mm.

Comparison of the two tally methods requires an understanding of how the two methods define the number of grid values per dimension. The TALLYX input requires the user to input the number of pixel boundaries per dimension. Therefore the number of pixels per dimension in the TALLYX input cards is one less than the number specified in the input. The number of voxels per dimension in the fmesh input is the same as the number specified in the input. The two-dimensional TALLYX output will have one more row and column of data than the fmesh data set. The largest number row and column of data in the TALLYX output must be dropped from the data set in order to compare the two sets of tally results. This same correction is used for comparing the TALLYX tally to the radiography tally. Verification that the omission of the largest row and column of data in the TALLYX data set correctly aligns the different radiography results will be shown in a future research note that quantifies the differences between the radiography tally, TALLYX tally, and the fmesh tally.

The transmission images for the entire set of cylindrical targets are given in Figure 4. The two-dimensional images and the line outs for the cylinders appear to give the same transmission results. The transmission through the cylinders is around 1×10^8 photons/cm^2. The difference between the two tallies is given by subtracting the TALLYX image from the fmesh image. The differences over the cylinders range from 1×10^6 to 6.0×10^6 photons/cm^2 with the mean difference value being around 3.75×10^6 photons/cm^2. The percentage difference ranges from 1% to slightly over 6%. The mean percentage difference is around 3.75 %. A small increase in the disparity between the two tallies occurs near the image edges formed from the collimation of the beam. One reason for the increased disparity is that the higher amount of scattering at the edges from the collimation of the beam creates larger angle trajectories at the edges. The larger the trajectory angle the greater the disparity between the two tally methods as seen in Figure 1. Another reason for the increase may be due to the poorer statistics for the tally in regions outside of the beam image. In Figure 8 a line out of the relative error of the tallies climbs to over twenty percent within a few pixels of the beam edge. Poorer statistics make the matching of tally results more difficult.

The transmission images for the tagged cell tallies of the cylinder target are given in Figure 5 for cylinder1, Figure 6 for cylinder 4, and Figure 7 for cylinder 6. The tagged cell tally plots for each tally method show the photon fluence transmitted through the specific cylinders to be approximately the same. The cylinder 6 tally is slightly smaller than the other two cylinders if the spikes at the outer edge of the cylinder are omitted. The photon fluence spikes at the outer edges of cylinder 6 in Figure 7 are limbing effects. Limbing effects are due to the increased scattering out of a more dense material into a less dense material. The scatter of photons out of the aluminum contributes to the transmitted flux near the edge of the target to significantly increase the particle count at the edge. The large density disparity between the aluminum and the air creates the large spike at the edges since the significantly lower density air will not scatter as many particles back into the aluminum as the aluminum will scatter out into the air. Therefore one can conclude that the increased transmission at the edges is not due to a decrease in target density and one can omit these effects when averaging the transmission across the cylinder. The net loss of scattered particles out of the aluminum at the edge decreases the total transmission through the outer cylinder. Therefore the average fluence seen in the line outs for cylinder 6 in Figure 7 is slightly less than the other tagged tally results. The general shape of the transmission through the tagged cells is consistent with the overall fluence through all cylinders seen in Figure 4. The tagged tallies appear less uniform due to scattering losses of tagged particles at the edges of the cylinders.

For cylinder 1 the average of the difference between the two tallies methods is less than 1%. The difference peaks at approximately 2.5%. The tagged cell tally for cylinder 4 has an average difference around 3%. The difference for cylinder 4 peaks at roughly 4%. The tagged cell tally for cylinder 6 has an average difference around 1.5%. The corresponding peak difference is around 3.5%. The largest disparity between the methods occurs for the photons tagged through cylinder 4 while the smallest difference occurs for the center cylinder (cylinder 1). The tallies are more consistent for the center cylinder since the angular trajectory of the photons increases as a function of radial position and therefore the portion of the beam striking the center cylinder is more parallel to the beam axis. Parallel trajectories measured in the fmesh tally give the same results as the TALLYX tally as seen in Figure 1. Extrapolating this logic for the other cylinders suggests that the outermost cylinder (cylinder 6) should have a larger difference between the tallies than cylinder 4 which has a smaller radius. The difference in cylinder 4 is greater due to the scattering in and out of cylinder 4 from cylinders 3 and 5. The photons scattered in and out of cylinder 4 have a larger angular dependence and this larger angular dependence increases the difference between the two tally methods. While cylinder 6 has a larger radius, it has no scattering into its outer surface from the surrounding air. The reduction in scattering therefore increases the consistency between the tally methods.

Line outs of the relative error are given in Figures 8, 9, 10, and 11. The axis limits for the pixels are varied to highlight the regions of interest. The fmesh and TALLYX relative error values are nearly identical for all cylinder plots except for the noisy regions away from the cylinders. The increase in the relative error away from the cylinders is due to the poor statistics from the lower transmission. The relative error for the entire cylinder in Figure 8 is at 0.005 at the outer radius and curves down to around 0.0045 in the middle. This profile for the relative error is consistent with the tagged cylinder relative error plots. The relative error for cylinder 1 is around 0.0045 in Figure 9. Cylinder 4 relative error in Figure 10 is also around 0.0045 (or slightly less) and cylinder 6 relative error averages around 0.005 in Figure 11. The difference of the relative errors for the entire cylinder in Figure 12 is around 4×10^{-5} on average with a maximum variation from the average of $\pm 7\times10^{-5}$. The tagged cell transmissions also have roughly the same average and variation. The cylinder 4 and 6 results have noisy regions away from the cylinders with significantly larger differences. The small tagged tally contributions in these noisy regions have poorer statistics that contribute to the larger differences. The magnitude of the relative error difference is roughly 1% of the relative error seen in Figures 8, 9, 10, and 11. The consistency of the relative errors shows that the same statistical accuracy can be achieved with the same number of particles for both methods. No adjustments need to be made in the number of particles run for identical simulations using the two tally methods.

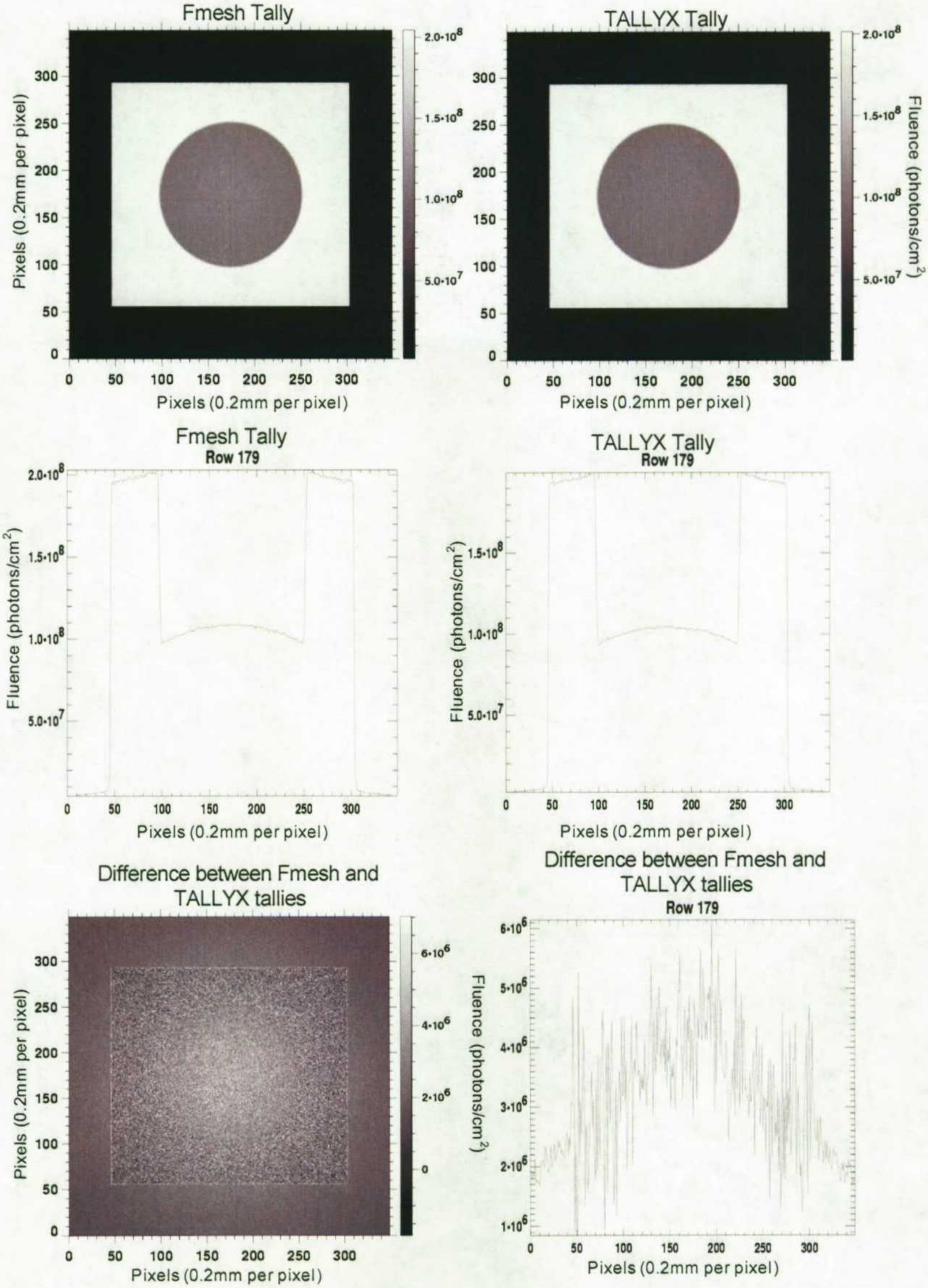

Figure 4 - Transmission images for the cylindrical target using the fmesh and TALLYX tallies.

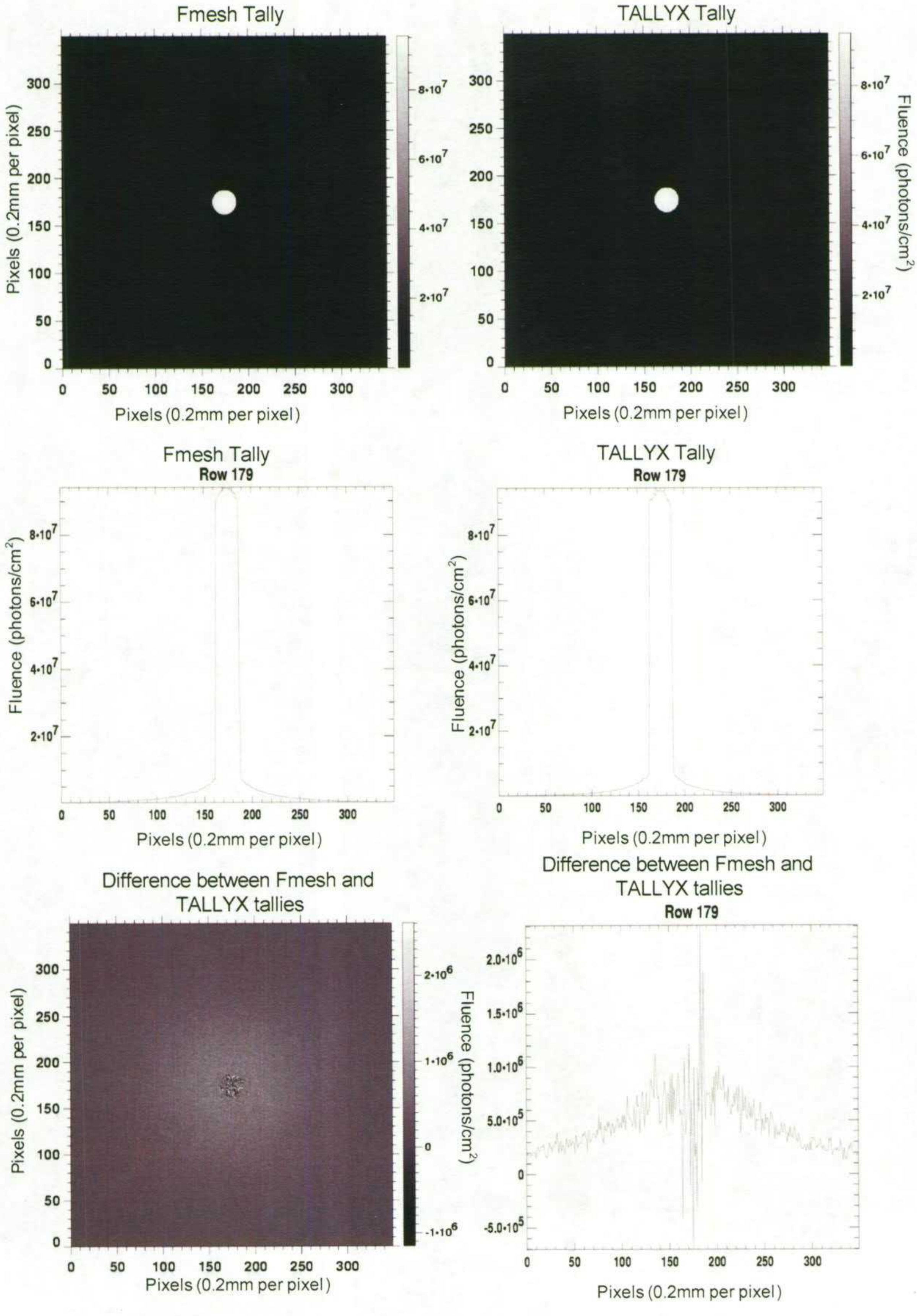

Figure 5 – Fmesh and TALLYX tagged cell tallies of cylinder 1.

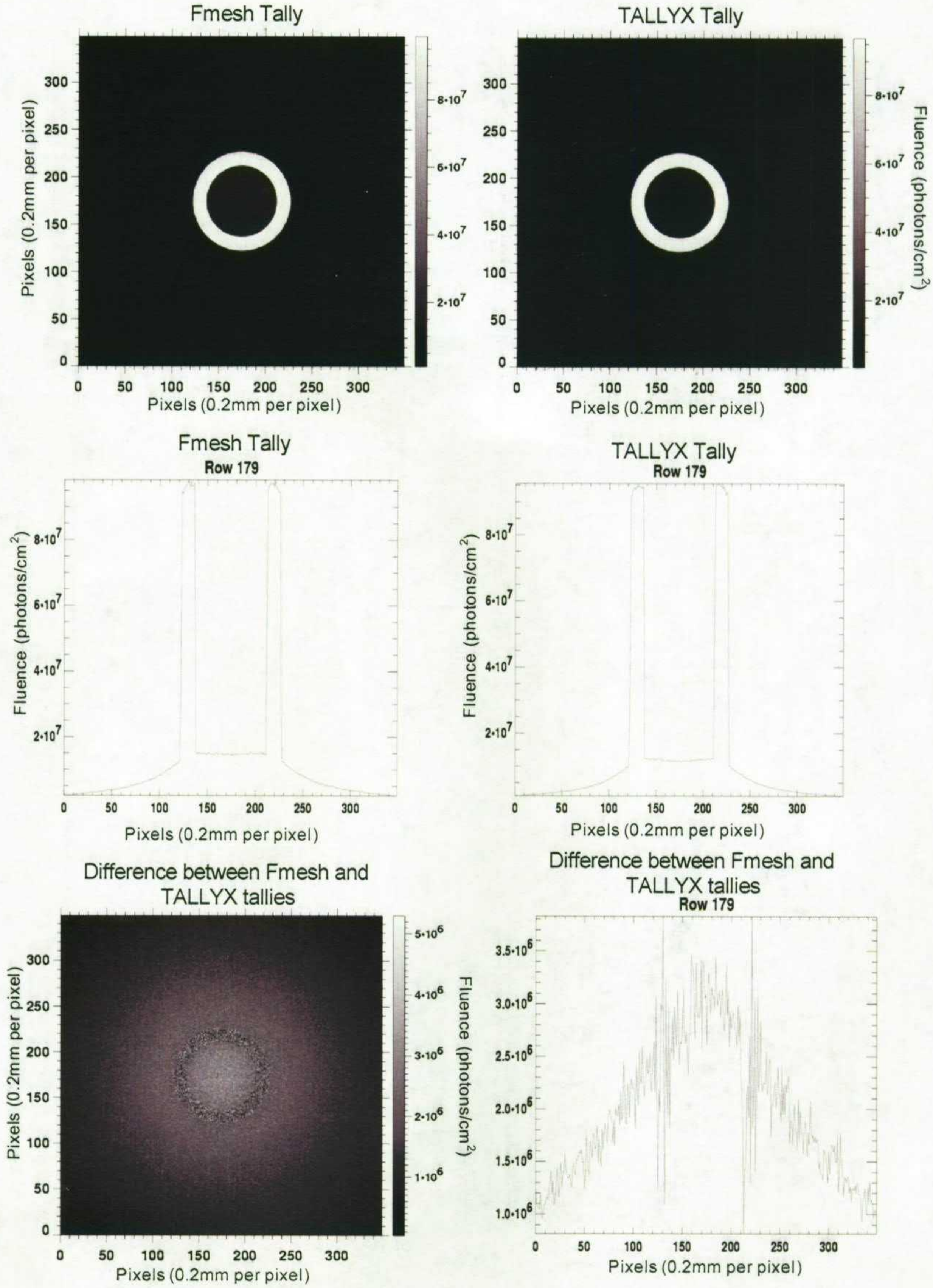

Figure 6- Fmesh and TALLYX tagged cell tallies of cylinder 4.

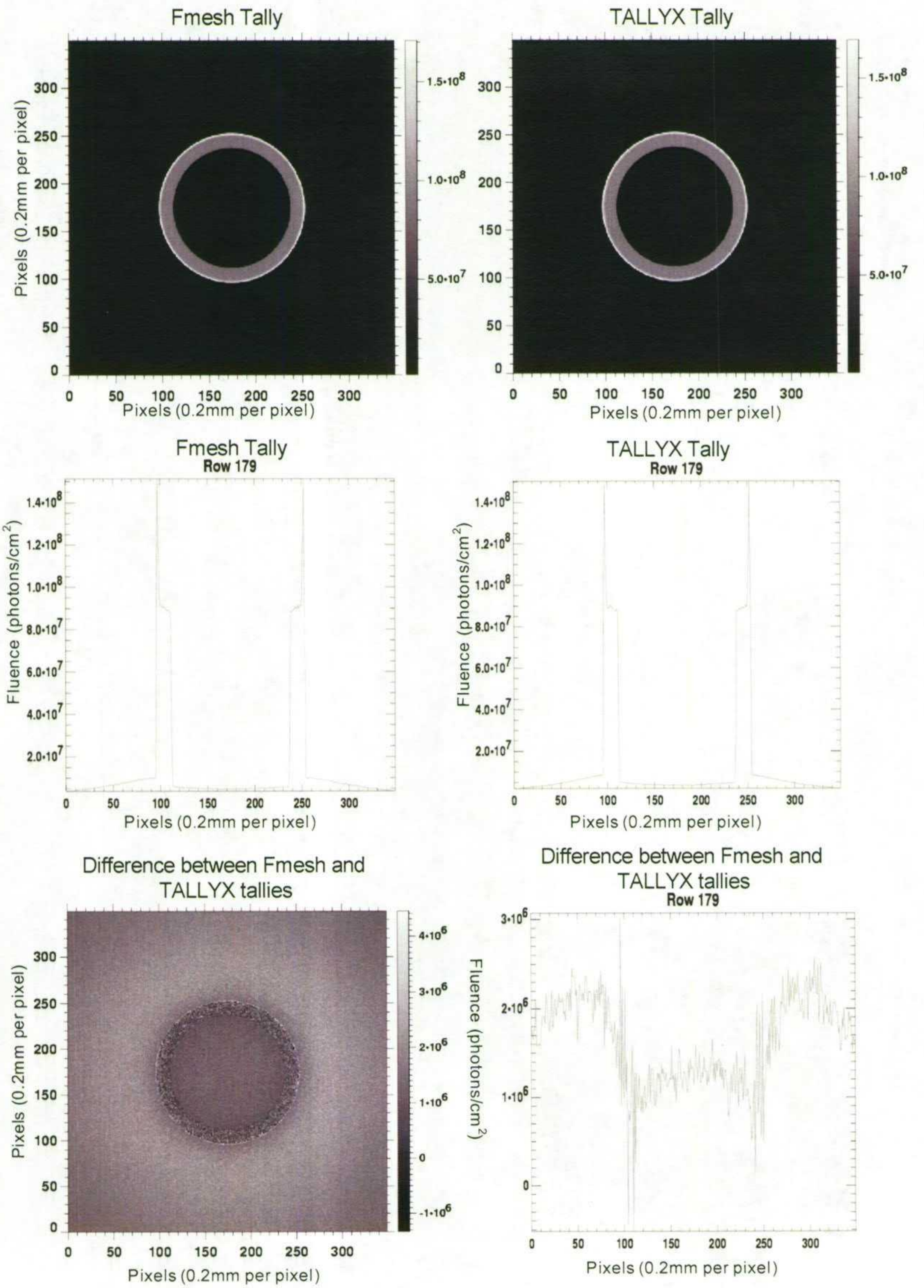

Figure 7- Fmesh and TALLYX tagged cell tallies of the outer cylinder (cylinder 6).

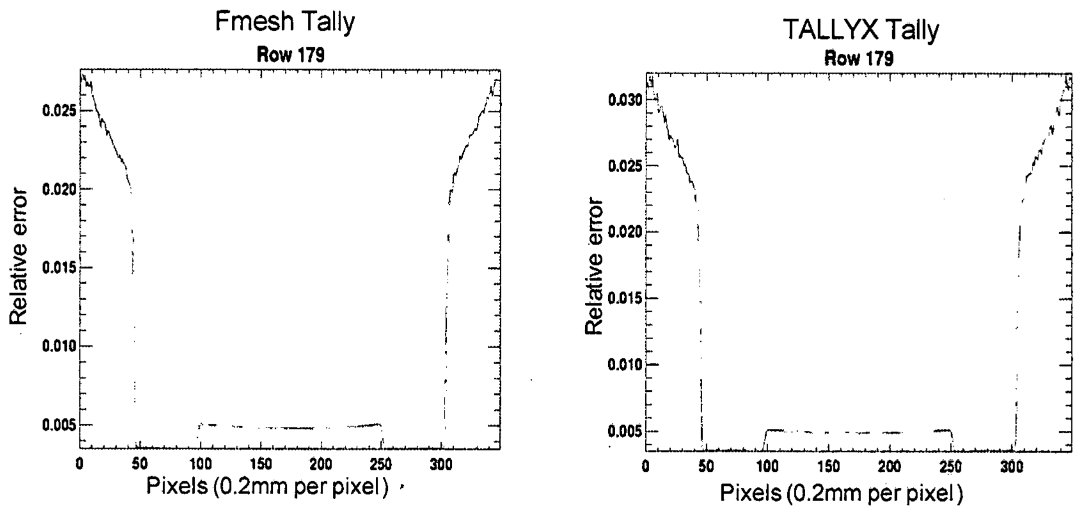

Figure 8- Line outs of the relative error of the fmesh and TALLYX tallies for the cylindrical target.

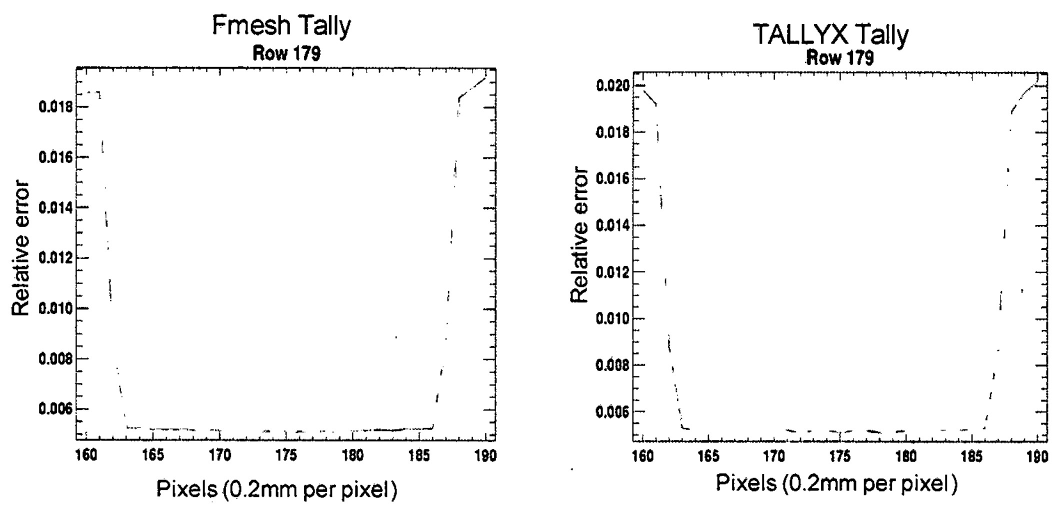

Figure 9- Line outs of the relative error of the fmesh and TALLY tallies for cylinder1.

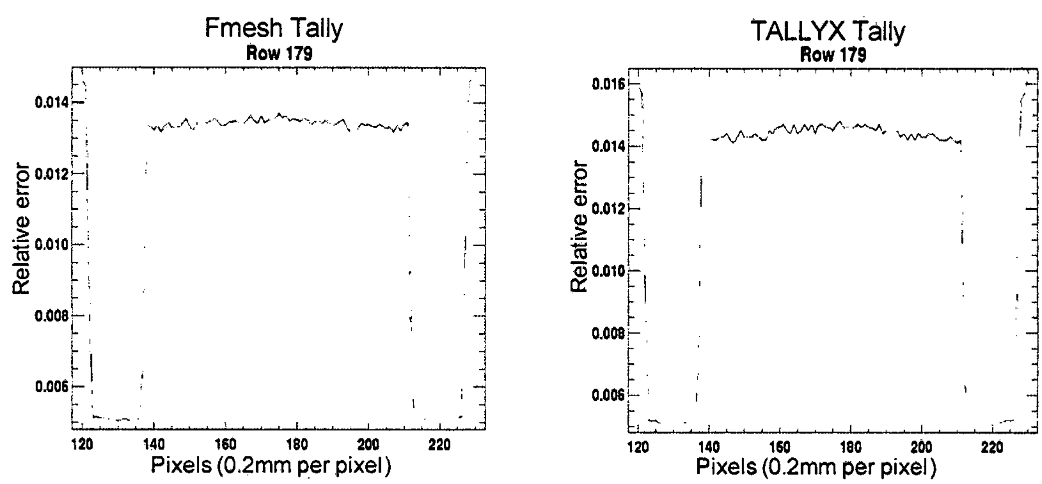

Figure 10- Line outs of the relative error for the fmesh and TALLYX tallies for cylinder 4.

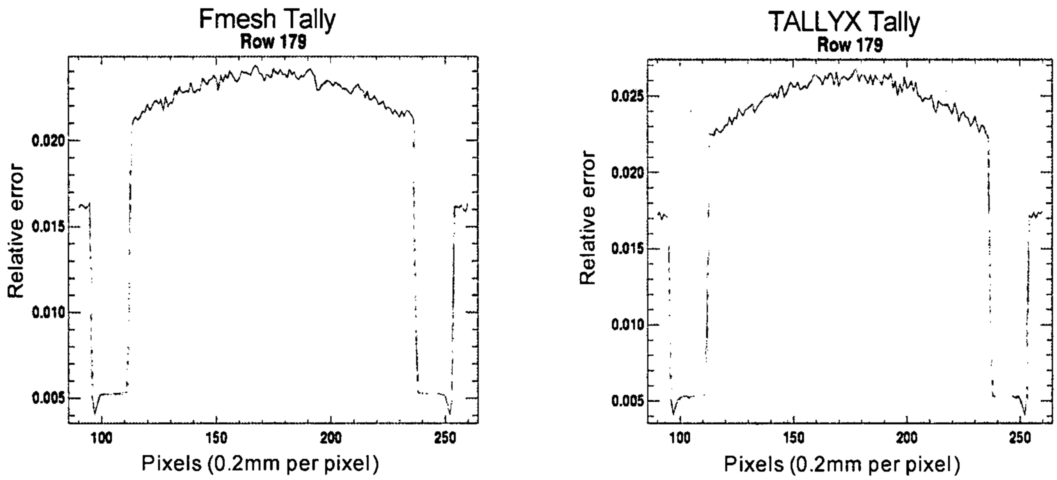

Figure 11- Line outs of the relative error for the fmesh and TALLYX tallies for cylinder 6.

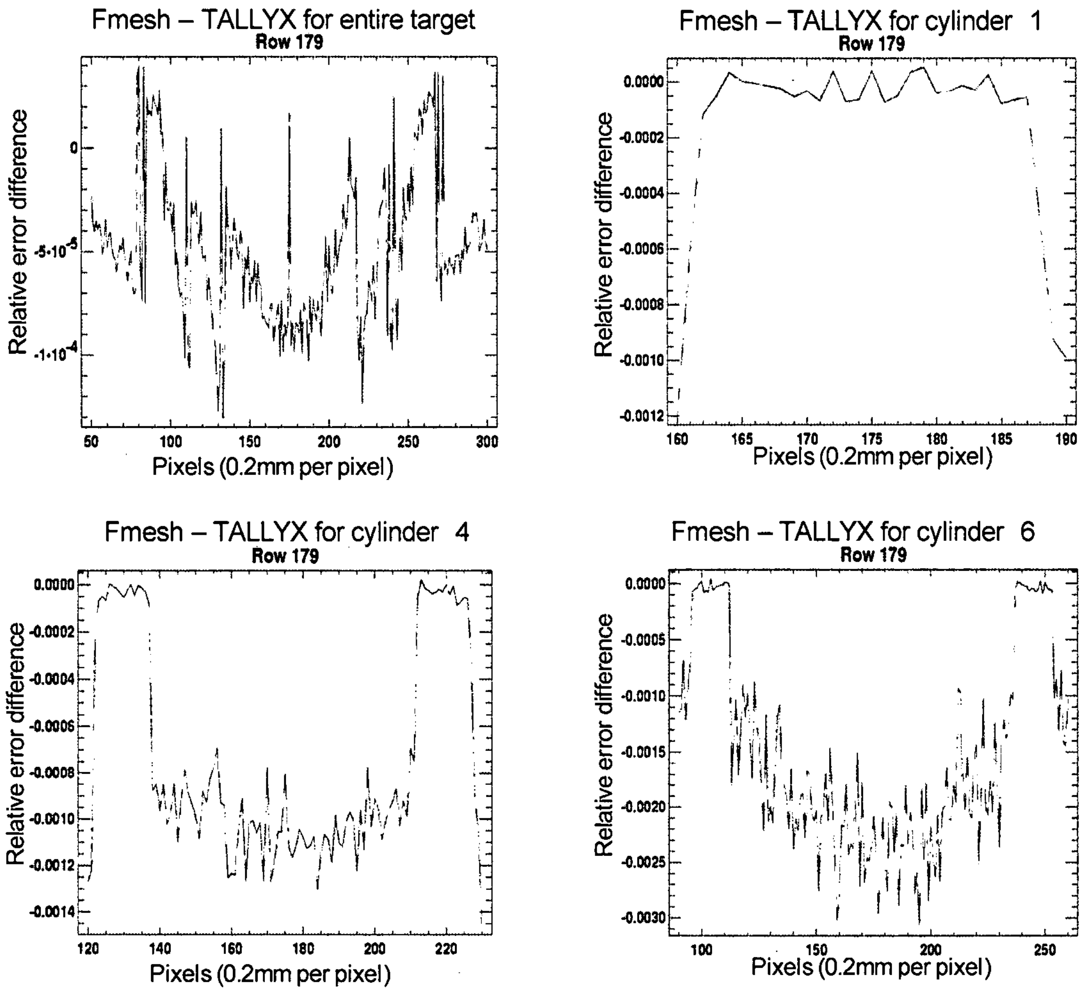

Figure 12- Line outs of the relative error difference between the fmesh and TALLYX tallies.

III. Conclusion

The overall comparison of the tagged tally results indicates the fmesh volumetric tally is consistent within a few percent of the TALLYX tally. The difference in the tagged tallies is consistent with the difference between the two tallies in general. The general difference in how the two methods tally particles is illustrated in Figure 1 and indicates the disparity between methods will always depend to some degree on the target and radiographic system. The sub percent difference for the center cylinder (cylinder 1) tagged cell results in Figure 5 shows that the two tally methods give nearly identical results when the particle trajectories measured in the fmesh volumetric tally are normal to the front surface of the voxel. Results seen in Figure 6 and Figure 7 verify that as the measured particle trajectories diverge from the front surface normal a larger difference between the tally results occurs. These results also show that other effects related to the increase in the angular dispersion of the photons, such as scattering at the target edges, also reduce the consistency between the tally methods.

Comparisons of the relative error of the tallies show that both tally methods give essentially the same statistical accuracy for the same number of particles. Statistical consistency between tally methods allows the same number of particles to be used for identical simulations for both tallies. The comparison of results from the two methods is therefore also easier to perform.

The quantification of the differences between the two tally methods for a system with realistic source properties (divergent beam, edge scattering effects, etc.) gives a general guideline for comparing simulated radiographs performed with the two different tally methods. Any comparison where the difference of the two tally methods exceeds a few percent indicates that other discrepancies may exist between the two simulations. An understanding of the source, sources of scattering, and the target characteristics must be weighed in any comparison. The consistency between tally methods seen in this analysis indicates that no capabilities will be lost or anomalies in results produced with the replacement of the TALLYX tally by the fmesh tally. The greater flexibility and more realistic measure associated with the fmesh tally make it the optimal tally method for use in most simulations.

References

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