Application of TITAN for Simulation of Particle Streaming in a Duct

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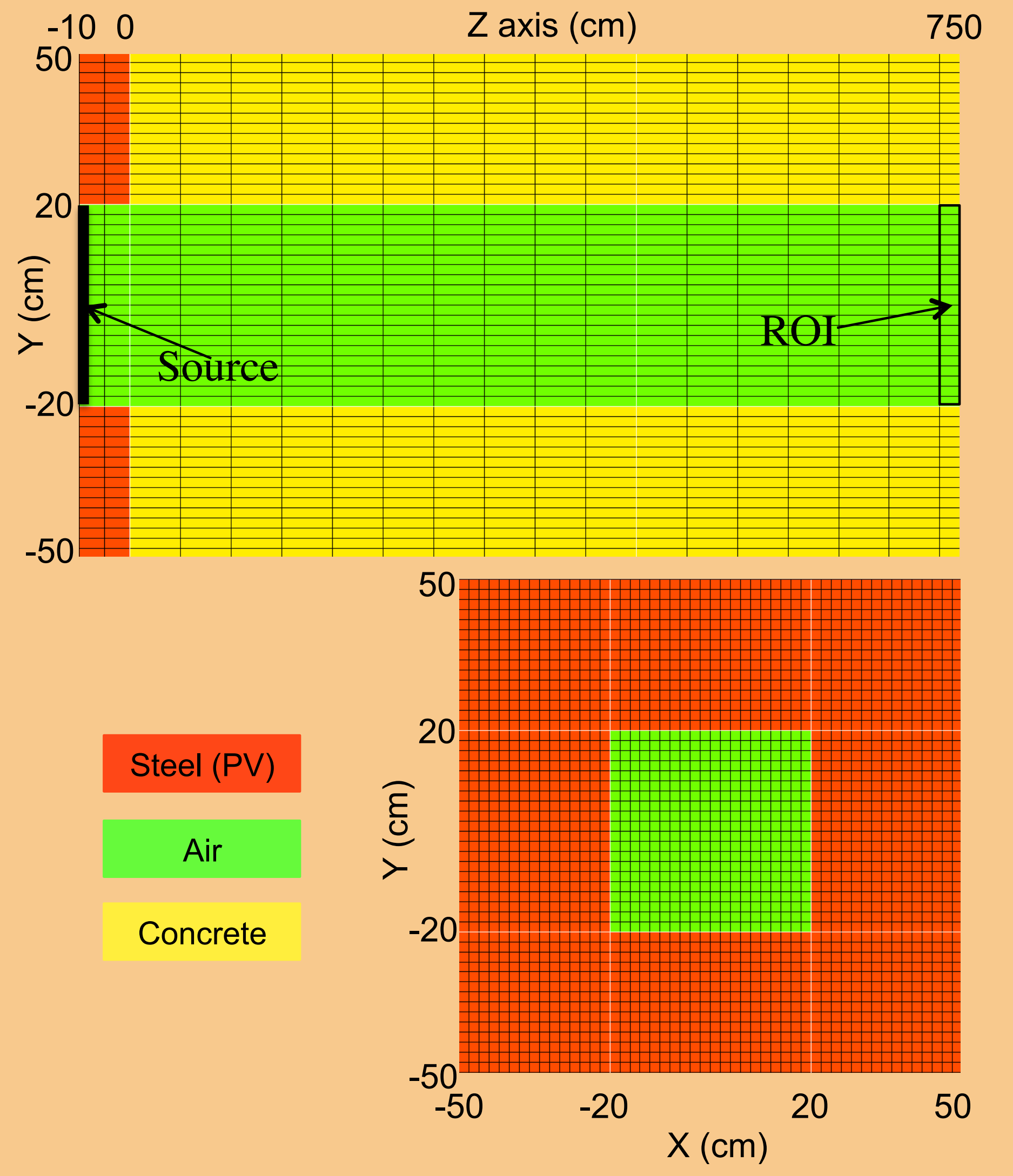
Introduction

Simulating particle streaming through a duct penetrating the pressure vessel in a BWR presents difficulties for both Monte Carlo and deterministic methods. In a Monte Carlo simulation, large computation times can be necessary to achieve reasonable statistical uncertainties because few particles will make it through the duct. In a deterministic simulation, memory can be a limitation, because of the angular and spatial discretization needed to represent a narrow duct. The TITAN deterministic transport code has hybrid methods that allow low scatter regions, e.g., air in a duct, to be efficiently represented. These methods are applied to a model of a duct leaving a pressure vessel.

Model

A simple concrete duct leaving a pressure vessel is modeled. An isotropic surface source with a U-235 fission spectrum is located at the pressure vessel end and the flux spectrum at the far end of the duct (ROI) is calculated. The BUGLE-96 47-group neutron cross-section library is used and the cross sections are converted to MCNP's multigroup format.



Duct geometry and base meshing with source and region of interest (ROI) (duct length along the z-axis not to scale)

Methods

Neutrons are transported through the duct using three different deterministic methods:

Case 1 TITAN discrete ordinates (S_N) only model

Case 2 TITAN S_N with characteristics method (CM) in air: The block spatial meshing in TITAN allows an S_N or CM solver to be specified in each region of a problem.

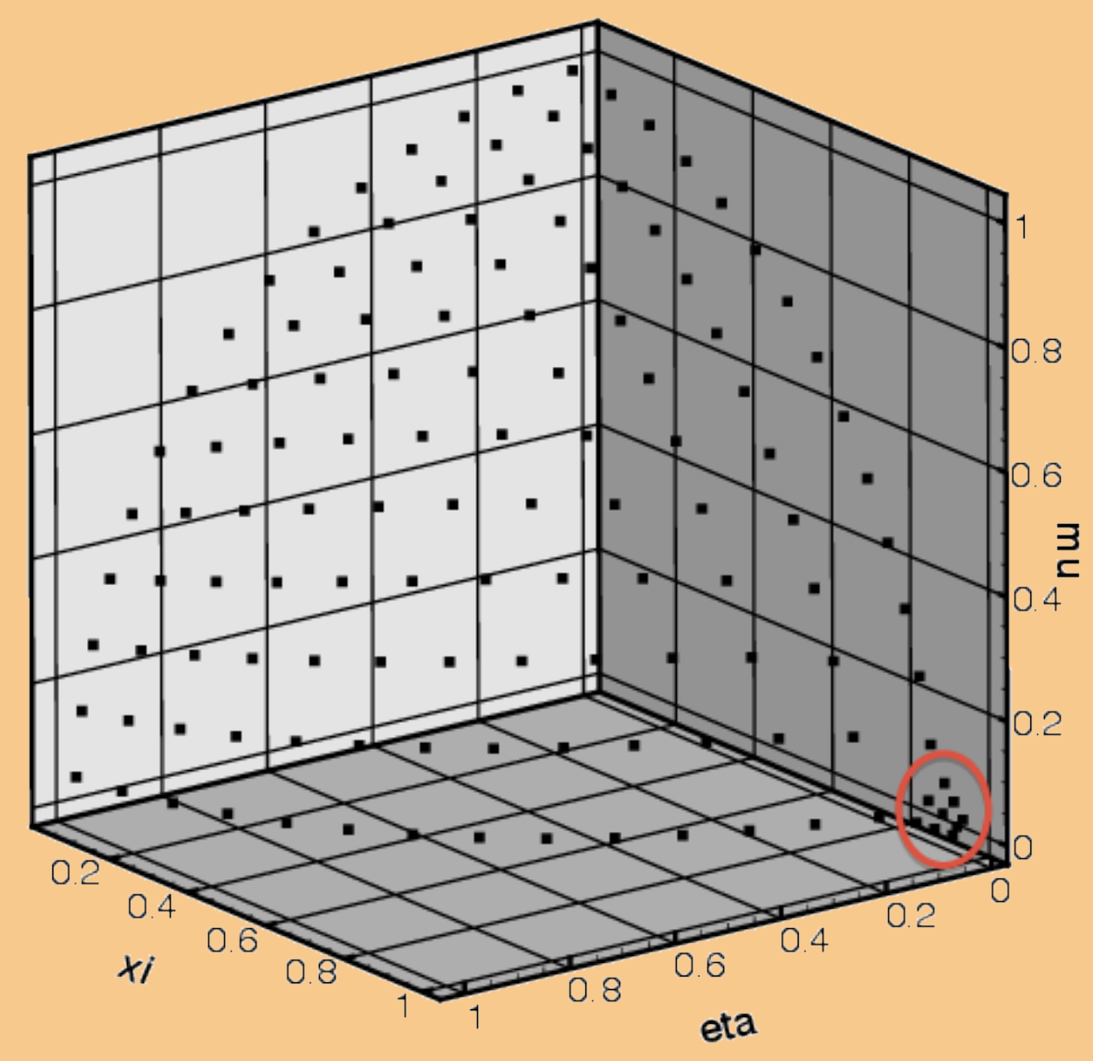
Case 3 TITAN S_N with fictitious quadrature and simplified ray-tracing model:

i) Discrete ordinates transport calculation with regular quadrature set
ii) Generation of fictitious quadrature set with circular ordinate splitting (COS)
iii) Extra transport sweep using converged flux moments from *i*) to evaluate scattering source
iv) Transport particles to ROI with fictitious quadrature set using simplified ray-tracing

$$S^{(e.s.)}_{scattering} = \sum_{g'=1}^{G}\sum_{l=0}^{L}(2l+1)\sigma_{s,g'\to g,l}\left\{P_l(\mu_n^{(fic)})\phi_{g',l}^{(con)} + 2\sum_{k=1}^{l}\frac{(l-k)!}{(l+k)!}P_l^k(\mu_n^{(fic)})\left[\phi_{C,g',l}^{k,(con)}cos(k\varphi_n^{(fic)}) + \phi_{S,g',l}^{k,(con)}sin(k\varphi_n^{(fic)})\right]\right\}$$

S_N Algorithm Studies

Studies with only the S_N solver were used to examine deterministic parameters. In particular, the *Ordinate Splitting* (OS) technique was used to reduce the number of directions needed.



S_{30} quadrature with ordinate splitting (red circle) of the direction closest to the z-axis (128 directions per octant)

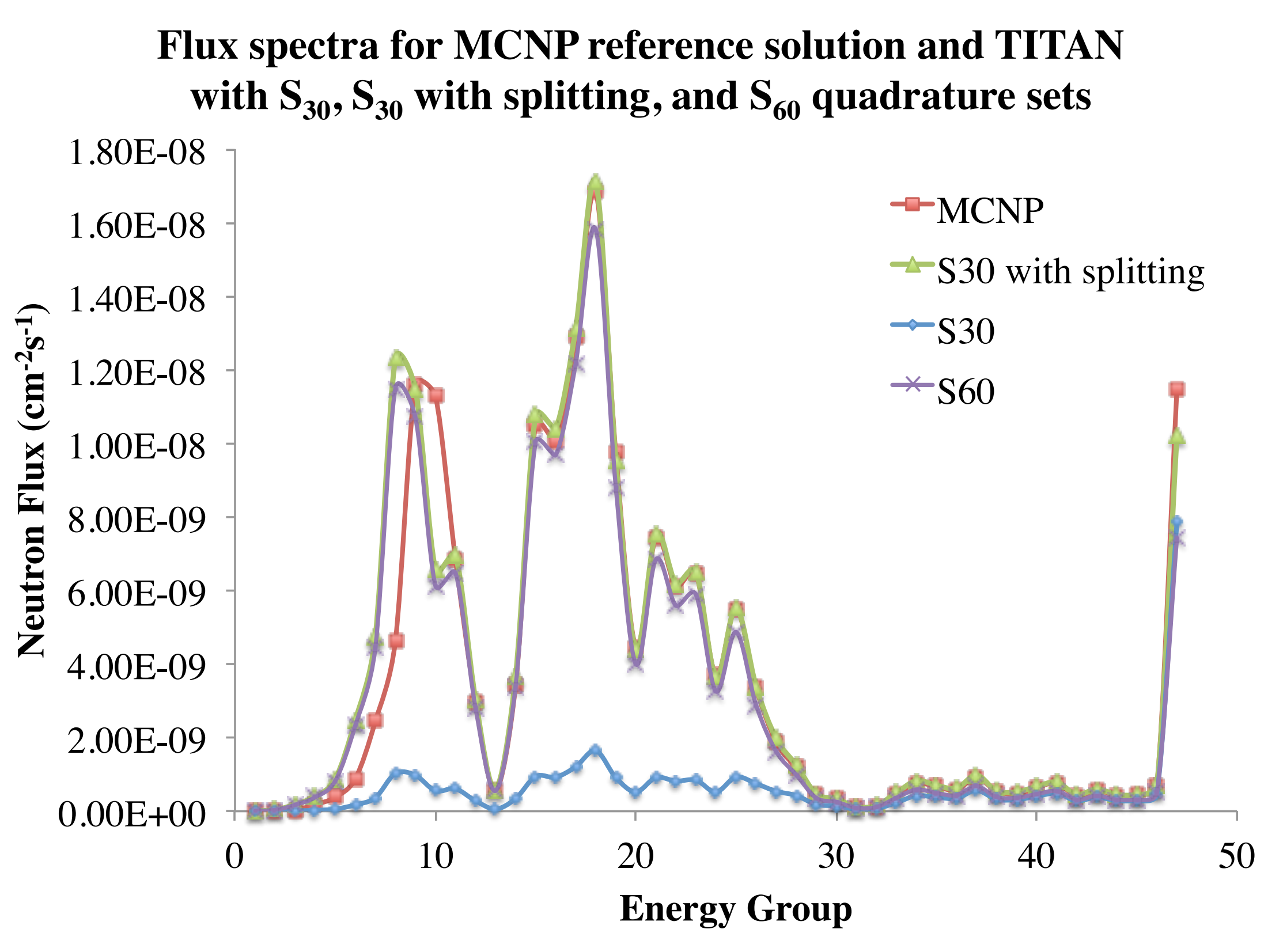


Table 1: TITAN number of directions, *total flux* difference relative to MCNP ($1\sigma = 0.05\%$), and computation time on 16 processors for S_N calculations with different quadrature sets

Quadrature Order	Number of Directions	Relative Difference	Computation Time (s)
S_{30}	960	-82.0%	3359
S_{30} with splitting	1024	5.21%	3479
S_{60}	3720	-5.73%	12406
S_{60} with splitting	3784	6.80%	12575

The S_{30} quadrature with splitting was determined to be accurate. Meshing studies determined that a coarser z-meshing could be used and resulted in choosing a model with 82,500 fine meshes.

Comparison of S_N only with Hybrid Methods

The TITAN solutions match the shape of the MCNP reference solution well. The MCNP solution does not follow the first peak in the source fission spectrum and this is believed to be due to the fact that the scattering moments in the multigroup cross sections cannot be directly used by MCNP. The TITAN result for the fictitious quadrature set is not accurate for low energy groups because the method does not model the concrete around the duct.

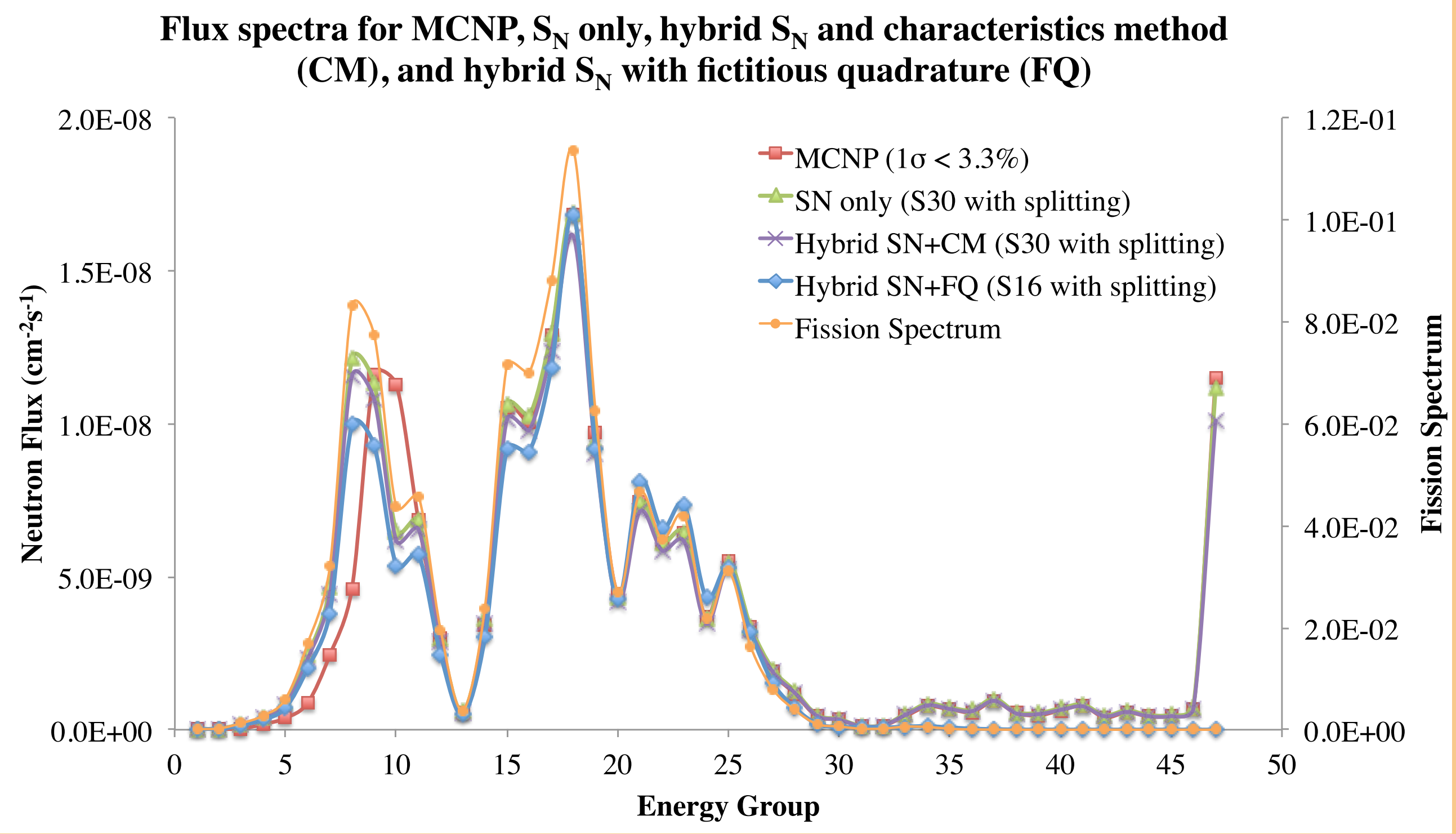
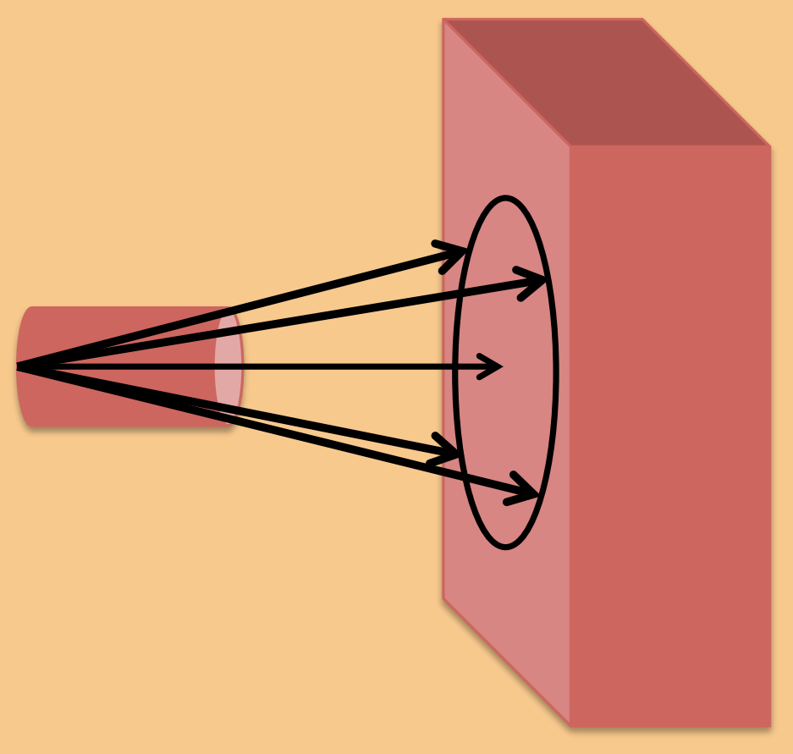


Table 2: Computation times for different methods and speedup relative to MCNP on 16 processors

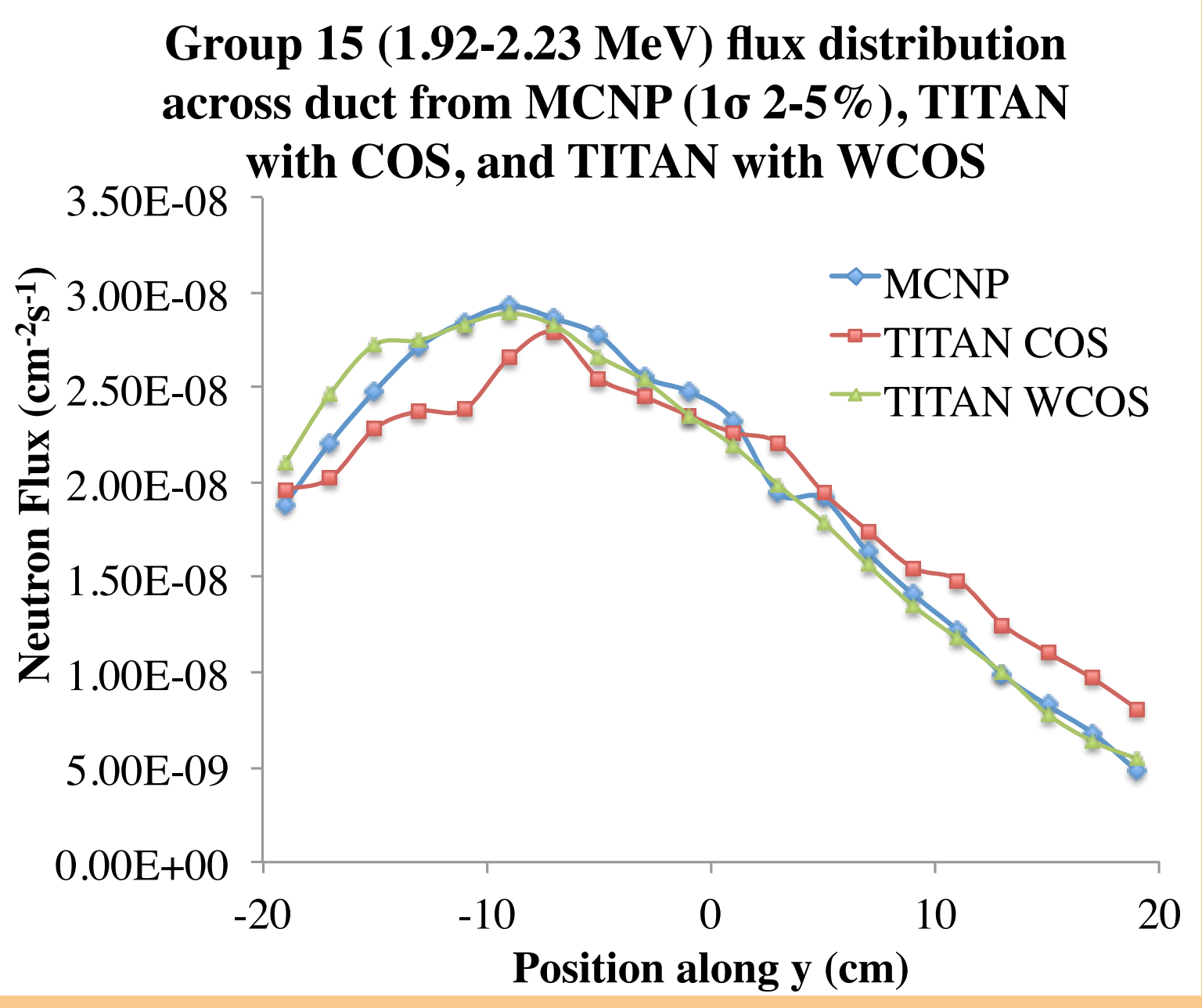
Method	Time (s)	Speedup
MCNP5	64010	—
TITAN S_{30}	1478	43.3
TITAN S_{30}+CM	1319	48.5
TITAN S_{16}+FQ	44	1471.5

Collimated Detector Results

The WCOS technique for simulating a collimator was examined for a neutron source that varies by a factor of ten across the opening of the duct. The WCOS solution is seen to improve upon the COS solution.



Circular ordinate splitting to represent collimation



Conclusion

The hybrid methods in the TITAN code have been applied to streaming of neutrons through a duct in a nuclear power plant. The ordinate splitting technique has been shown to significantly reduce the number of directions needed to accurately model the duct and therefore reduce computation time. Three different methods of modeling the duct in TITAN have been demonstrated: S_N only, S_N and CM, and S_N with fictitious quadrature set. The calculated spectra at the end of the duct have been compared with a reference Monte Carlo solution. The S_N only and S_N and CM spectra have average absolute relative differences of 5.0% and 4.1%, respectively, relative to MCNP for energies less than 2.7 MeV (group 11). The TITAN solution methods have speedups of 43-1471 over the MCNP computation time.

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