# A Numerical Approach to Calculate In-Depth Penetration of Radiative Heating in Thermal Protection System (TPS)

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## Objective

Develop a massively scalable Monte Carlo radiation (SPARTA-rMC) code to simulate radiative transport through real complex materials.

## Introduction

Space vehicles entering a planet's atmosphere attain hypersonic speeds (M>10). At such high-speeds, extreme thermal conditions are experienced and a TPS material is required to protect the vehicle from overheating.

Figure: 1. Atmosphere Re-entry of a space vehicle

It had been previously believed that the incoming shock-layer radiative flux was either reflected at the surface or absorbed within a 1 mm thickness of the surface [4]. Since most heritage TPS are far thicker than this 1 mm absorption zone, the penetration of radiation within the TPS has always been neglected. However, new experimental work shows that spectral radiation can penetrate the TPS and affect the material response over a significant depth, with higher intensity emissions penetrating deeper into the TPS [5]. As the temperature across the TPS increases, the thermal decomposition (pyrolysis) of the phenolic resin creates a porous network and increased penetration is observed in the decomposed (char) zone. Understanding radiative transport is therefore, essential to designing a reliable TPS material.

## Theory

In a Monte Carlo radiation code, the photons are tracked using the ray tracing approach. When the photon encounters an object in its path, a decision tree determines scattering, transmission, or absorption depending on the probabilities and efficiencies determined from quantum and classical mechanics theory and the event occurrences are determined stochastically.

## Methods

A geometric optics approach has been implemented in the Sparta-rMC code. Once the code imports the microstructure geometry then photons are generated within the domain. Using the Monte Carlo ray trace method, the extinction and absorption coefficients are calculated by summing the extinction length and the absorption length computed from the photon's mean free path [1].

## Central Idea

Developing a microscale approach to compute optical properties of multi-phase material microstructures, followed by a macroscale analysis of radiative transport.

## Results

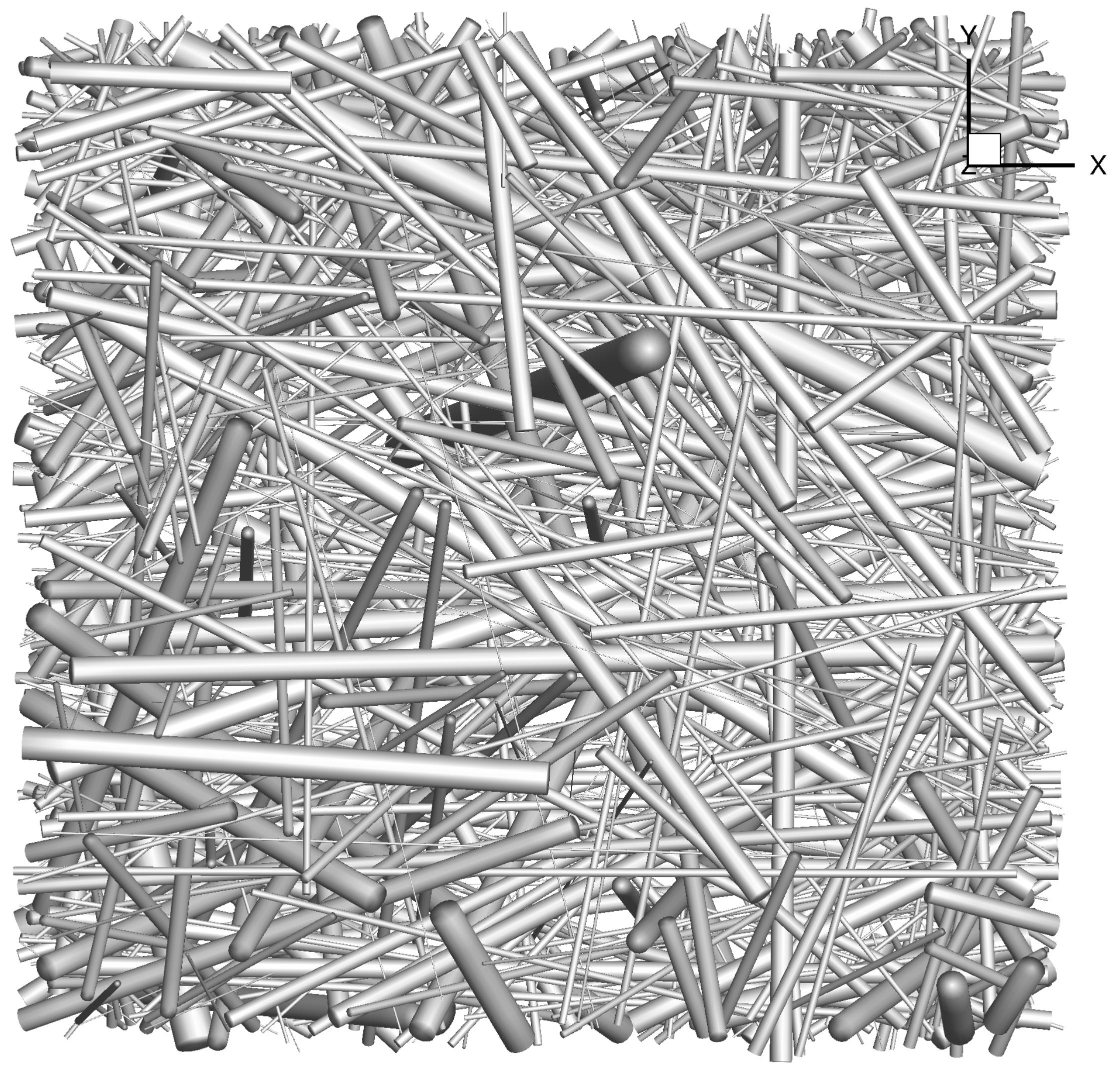

Figure: 2. Microstructure of LI 900 TPS Material

→ LI 900 is a TPS material which is essentially Silicon Dioxide. It consists of a fibrous network of infinitely long cylinders with diameter of 5 micron with variable standard deviation and porosity 0.94.

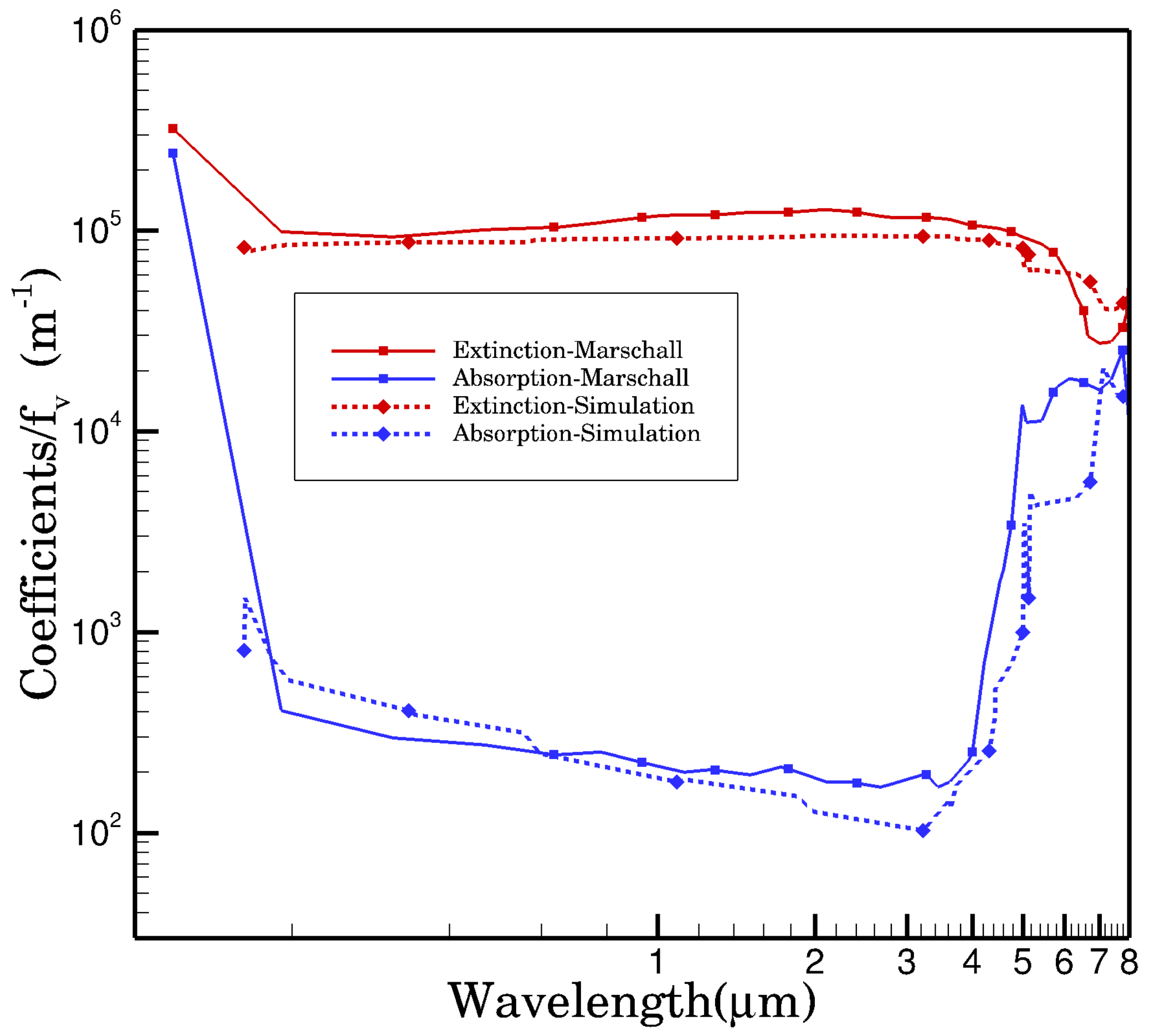

Figure: 3. Comparison of optical coefficients with Marschall

→We have compared our work with the results of Marschall [2].

→With confidence in our results, we move forward to generate the optical properties for different TPS material.

## Conclusion

With the validation of the Sparta-rMC code, we will generate optical properties for various heat shield materials. Fig.4 shows the microstructure of cylinders and micro-balloons. These optical properties will serve as an input to the solve the Radiative Transport Equation from which the penetration depth will be determined.

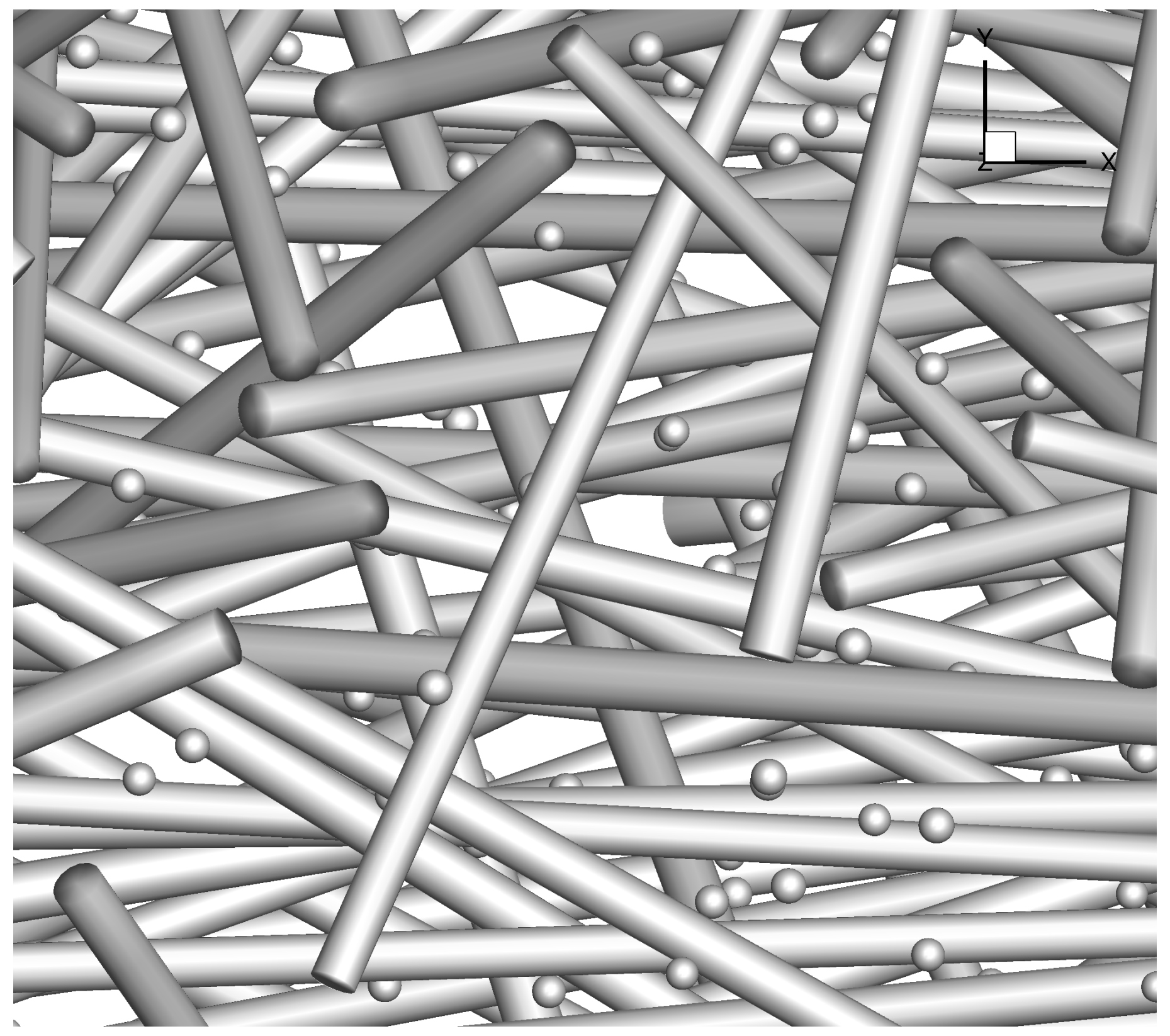

Figure: 4. Cylindrical and micro-balloon geometry Fibergen [3]

## References

[1] S. Cunsolo et al. *International Journal of Thermal Sciences* 104 (2016), pp. 122–134.

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[4] S. White. *Journal of Spacecraft and Rockets* 49.5 (2012), pp. 889–893.

[5] S. White. *38th Annual Conference on Composites, Materials and Structures*. 2014.

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