

Calculating the Expected Effective Multiplication Factor and Neutron Scalar Flux Profile in Statistically Homogeneous Random Media Using a Nonclassical Model

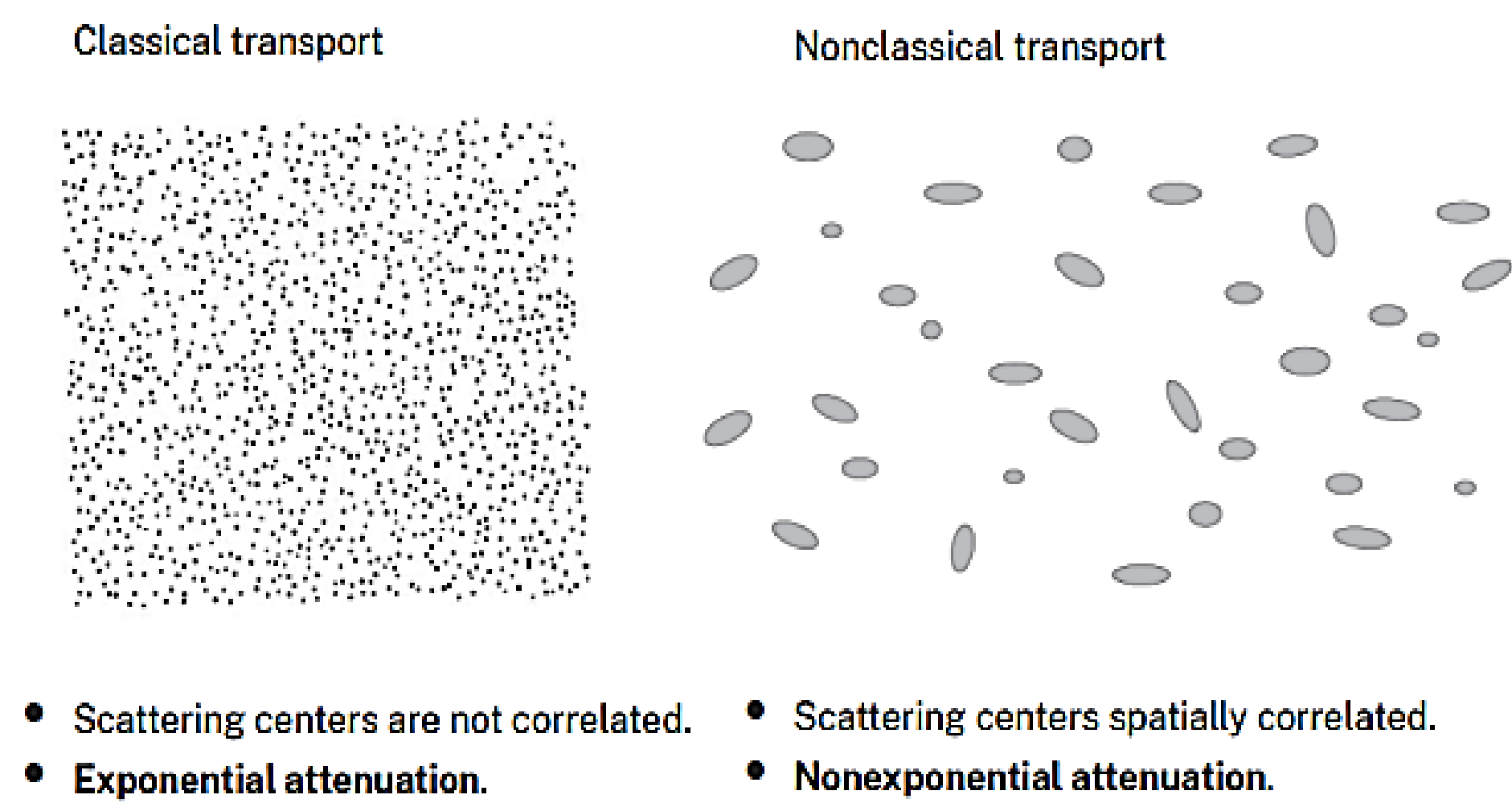
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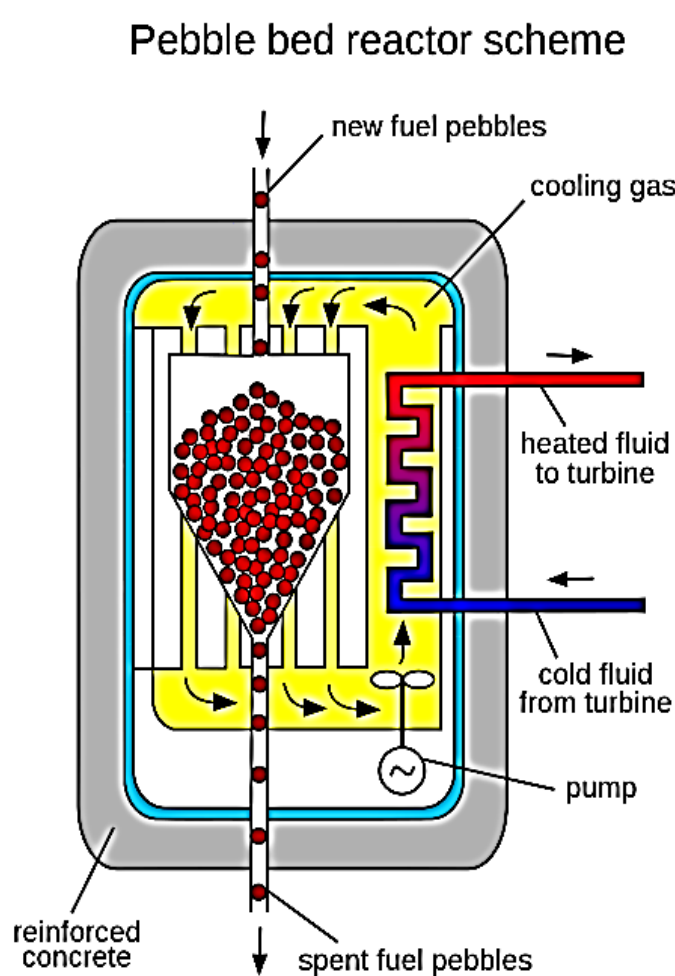
I – Introduction

- The transport phenomena may exhibit varied behavior contingent upon the spatial arrangement of the medium.



- The transport problem on the right resembles the core of Pebble Bed Nuclear Reactors.

- Traditional computer codes rely on the classical transport model, which inherently assumes an exponential attenuation for the particle flux. This scenario prompts the expansion of the nonclassical transport models to address criticality problems.



II – Mathematical Methodology

- In the nonclassical model, the incremental probability dp that a particle will collide while traveling an incremental distance ds is given by $dp = \Sigma t(\mathbf{x}, \mathbf{\Omega}, s)ds$, where $\mathbf{x}$ is a point of space, $\mathbf{\Omega}$ is the particle's direction of flight and s is the path-length.
- Considering $N(\mathbf{\Omega}, s)$ and $N(\mathbf{\Omega}, s + ds)$ as the number of particles that have traveled a distance s and $s + ds$, respectively, in the direction $\mathbf{\Omega}$ without experiencing collisions, we have

$$\begin{aligned}
 N(\mathbf{\Omega}, s + ds) &= N(\mathbf{\Omega}, s) + \frac{\partial}{\partial s} N(\mathbf{\Omega}, s)ds, \\
 -\frac{N(\mathbf{\Omega}, s) - N(\mathbf{\Omega}, s + ds)}{N(\mathbf{\Omega}, s)} &= \frac{1}{N(\mathbf{\Omega}, s)} \frac{\partial}{\partial s} N(\mathbf{\Omega}, s)ds, \\
 -\Sigma_t(\mathbf{\Omega}, s)ds &= \frac{1}{N(\mathbf{\Omega}, s)} \frac{\partial}{\partial s} N(\mathbf{\Omega}, s)ds, \\
 \frac{\partial}{\partial s} N(\mathbf{\Omega}, s) + \Sigma_t(\mathbf{\Omega}, s)N(\mathbf{\Omega}, s) &= 0, \\
 N(\mathbf{\Omega}, s) &= N_0(\mathbf{\Omega})e^{-\int_0^s \Sigma_t(\mathbf{\Omega}, s')ds'}.
 \end{aligned}$$

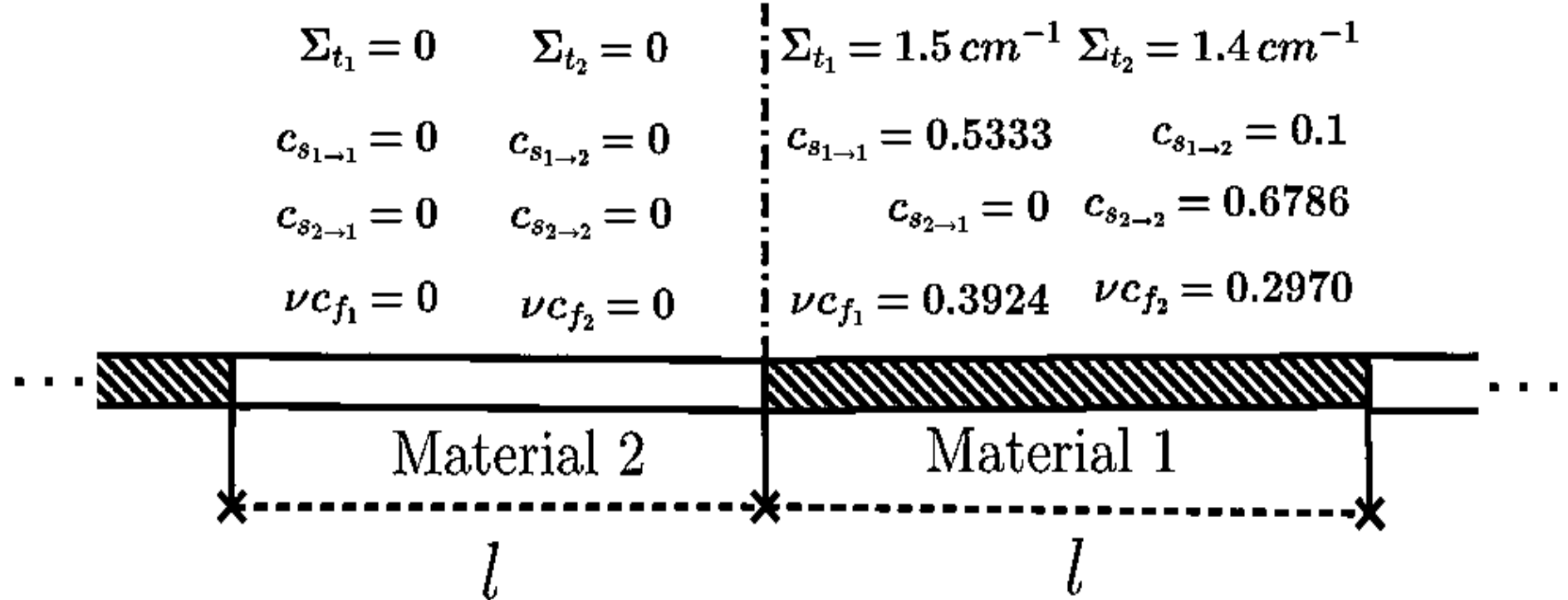
- Expanding the cross-section phase-space to include variable s enables the modeling of transport problems where nonexponential attenuation holds. Following this phase-space extension, a generalized linear Boltzmann equation (GLBE) for nonclassical criticality problems was derived. In its one-dimensional form, the nonclassical transport equation appears in the energy multigroup and discrete ordinates as

$$\begin{aligned}
 \frac{\partial}{\partial s} \Psi_{m,g}(x, s) + \mu_m \frac{\partial}{\partial x} \Psi_{m,g}(x, s) + \Sigma_{t_{m,g}}(s) = \\
 \delta(s) \left[\frac{1}{2} \sum_{n=1}^N \omega_n \sum_{g'=1}^G \left(c_{s_{g' \rightarrow g}} + \frac{\chi_g \nu c_{f_{g'}}}{k_{eff}} \right) \int_0^\infty \Sigma_{t_{n,g'}}(s') \Psi_{n,g'}(x, s') ds' \right], \quad \begin{matrix} m = 1 : N, \\ g = 1 : G. \end{matrix}
 \end{aligned}$$

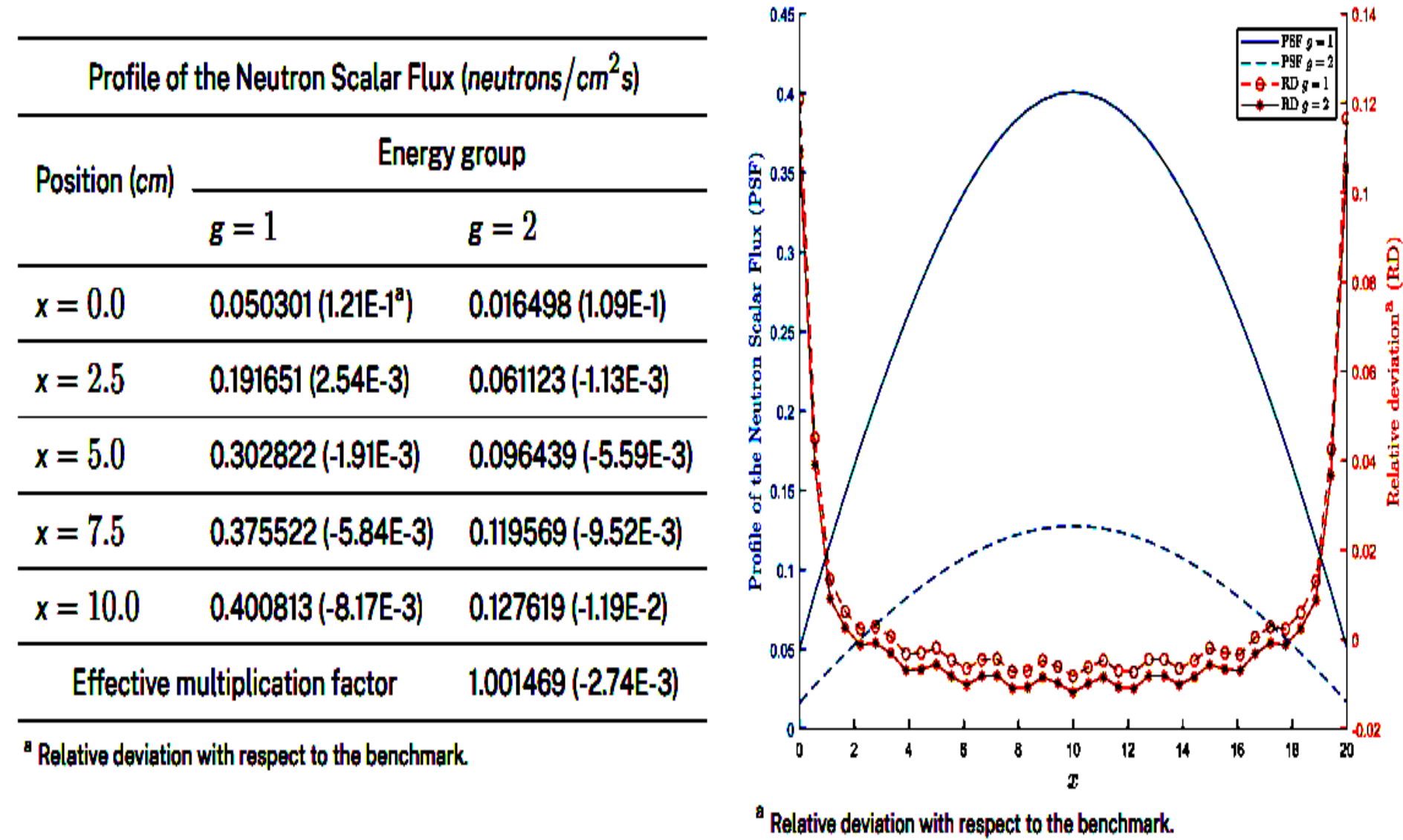
- The process used to generate the desired results from the GLBE involves applying the Spectral Approach to handle the s -dependence, the Response Matrix method to address the x -dependence, and the Power Iteration method to update the expected effective multiplication factor.

III – Numerical Results

- To illustrate the methodology's accuracy to reproduce the expected value for the system's effective multiplication factor and the profile of the neutron scalar flux, let us consider the following problem.



- This periodic system is randomly placed in the infinite line $-\infty \leq x \leq \infty$, such that the probability of finding any material is $1/2$. The expression for the total cross section can be found in the extended abstract.



IV – Trends in the Future

- The methodology proposed for addressing nonclassical criticality problems shows promising potential, indicating avenues for future research, such as: (i) Incorporating considerations for finite systems; (ii) Improving the robustness of the chosen methods to handle x and s -dependences; and (iii) Extending the methodology to multidimensional problems.

Acknowledgments

