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Progress in the formulation of the approximate albedo boundary conditions for one-speed *X*,*Y*-geometry discrete ordinates and diffusion eigenvalue problems

Ricardo C. Barros [a,*], Hermes Alves Filho [a], Nozimar do Couto [b]

[a] *Departamento de Modelagem Computacional, Instituto Politécnico, IPRJ, Universidade do Estado do Rio de Janeiro, UERJ, Rua Alberto Rangel s/n, 28630-050 Nova Friburgo, RJ, Brazil*
[b] *Comissão Nacional de Energia Nuclear, Rua General Severiano 90, 22290-901 Rio de Janeiro, RJ, Brazil*

Abstract

We discuss in this paper the efficiency of approximate discrete ordinates (S_N) and diffusion albedo boundary conditions for one-speed eigenvalue problems in *X*,*Y* geometry. The non-standard S_N and diffusion albedos substitute approximately the baffle–reflector system around the active domain, as we neglect the transverse leakage terms within the two non-multiplying regions. Should the problem have no transverse leakage terms, i.e., one-dimensional slab geometry, then the offered albedo boundary conditions are exact. By efficiency we mean analyzing the accuracy of the numerical results versus the CPU execution time of each run for a given model problem. Numerical results to typical test problems are shown to illustrate this efficiency analysis.
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1. Introduction

In a critical nuclear reactor, there is a balance between the number of neutrons produced in fission and the number lost, either by absorption in the reactor core or by leaking from its surface. One of the central problems in the design of a nuclear reactor is the calculation of the size and composition of the system required to maintain this balance. Calculations of the conditions necessary for criticality are traditionally carried out using neutron transport or neutron diffusion theory. The transport and diffusion theory methods which have evolved over the years for making nuclear reactor global calculations are eigenvalue problems that provide the effective multiplication factor (k_{eff}), defined as the dominant eigenvalue, and the stationary neutron flux distribution (fundamental mode) at selected times during the lifetime of the core. Thus, the problem of finding the effective multiplication factor and the neutron flux distribution is that of solving an eigenvalue problem using time-independent neutron transport or diffusion equation as the mathematical model.

* Corresponding author. Tel.: +55 22 25288545; fax: +55 22 25288536.
E-mail address: rcbarros@pesquisador.cnpq.br (R.C. Barros).

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Neutron fission events do not take place in the non-multiplying regions of nuclear reactors, e.g., moderator, reflector, and structural core; therefore we claim we can improve the efficiency of nuclear reactor global calculations by eliminating the explicit numerical calculations within the non-multiplying regions around the active domain. In this paper, we present the recent advances in the application of non-standard *albedo* boundary conditions for two non-multiplying regions, e.g., baffle–reflector system around a thermal nuclear reactor core, using both the one-speed discrete ordinates (S_N) neutron transport and the neutron diffusion formulations. *Albedo*, the Latin word for ''whiteness'', was defined by Lambert (1760) as the fraction of incident light reflected diffusely by a surface (Pannekoek, 1961). This Latin word has remained the usual scientific term in astronomy. In the present paper, we extend it to the reflection of neutrons.

In deriving the two-region S_N albedo matrix, we transverse integrate the one-speed S_N equations in X,Y geometry inside the baffle–reflector system contiguous to the active boundary cell of the spatial grid setup on the domain (Alves Filho and Barros, 2002, 2005). That is, for the x direction, we integrate the S_N equations inside the baffle–reflector system in the y direction, neglect the transverse leakage terms and solve the resulting homogeneous ''one-dimensional'' transverse-integrated S_N nodal equations in the x direction analytically by performing a spectral analysis (Alves Filho and Barros, 2002). Therefore, this method is referred to as the spectral Green's function (SGF) method that can relate in a simple way the neutron angular fluxes backscattered into the active cell to the neutron angular fluxes entering the baffle from the active cell, since vacuum boundary conditions apply on the outer boundaries of the reflector regions.

As with the two-region diffusion albedo, we proceed similarly. That is, we transverse integrate the one-speed diffusion equation in X,Y geometry inside the baffle–reflector system, neglect the transverse leakage terms and solve the resulting ''one-dimensional'' equation analytically, following steps similar to the ones presented previously for the S_N model.

We remark that the only approximation that we consider in the derivation of the one-speed two-region albedos for monoenergetic S_N and diffusion eigenvalue problems in X,Y geometry is the neglect of the transverse leakage terms. Therefore, should this approximation introduce no significant errors, we expect the use of the present non-standard albedo boundary conditions to improve the efficiency of S_N and diffusion codes for criticality calculations, in the sense that we expect them to generate accurate numerical results in shorter CPU time. Clearly, for one-dimensional slab-geometry problems, where there is no transverse leakage, the present albedo boundary conditions are exact.

At this point, we present an outline of the remainder of this paper. In Section 2, we describe the mathematical preliminaries of the two-region albedo boundary conditions for use in S_N and diffusion codes for nuclear reactor global calculations. In Section 3, we present numerical results to analyze the efficiency of the offered albedo boundary conditions for S_N and diffusion eigenvalue problems. In Section 4 we present a number of general conclusions and suggestions for future work.

2. Mathematical preliminaries

In this section we describe the mathematical preliminaries of the two-region albedo boundary conditions for numerically solving one-speed X,Y geometry S_N (Section 2.1) and diffusion (Section 2.2) eigenvalue problems.

2.1. The one-speed S_N model

Let us consider a rectangular spatial grid Ω, where each cell $\Omega_{i,j}$ has width h_i and height k_j, with $i = 1{:}I$ and $j = 1{:}J$, viz Fig. 1. Now, we consider the one-speed S_N equations in X,Y geometry with isotropic scattering

$$\mu_m \frac{\partial}{\partial x}\psi_m(x,y) + \eta_m \frac{\partial}{\partial y}\psi_m(x,y) + \sigma_T \psi_m(x,y) = \sigma_S \sum_{n=1}^{M} \psi_n(x,y) w_n,$$
$$x_a < x < x_c,\ \ y_{j-1/2} < y < y_{j+1/2},\ \ m = 1:M,\ \ M = N(N+2)/2. \tag{1}$$

Here the notation is standard (Lewis and Miller, 1993) and Eq. (1) holds inside a homogeneous non-multiplying medium, e.g., baffle and reflector regions around a thermal nuclear reactor core. By integrating Eq. (1) inside the baffle, cf. Fig. 1, we obtain the familiar discretized spatial balance S_N equations

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