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Evaluating importance maps for TRIPOLI-4[®] using deterministic or on-line methods

Davide Mancusi¹, Michel Nowak¹, and Éric Dumonteil²

¹*Den-Service d'études des réacteurs et de mathématiques appliquées (SERMA), CEA, Université Paris-Saclay, F-91191, Gif-sur-Yvette, France*

²*IRSN, 31 Avenue de la Division Leclerc, 92260 Fontenay-aux-Roses, France*

Introduction

Monte-Carlo particle-transport codes are often the tool of choice for performing quantitative radiation-protection studies. However, the estimation of the response of a particle detector in a strongly attenuated radiation field is very computationally intensive. Radiation-protection problems, by definition, fall into this class, and are therefore intractable with Monte-Carlo methods unless suitable variance-reduction techniques are applied.

A common need for variance-reduction methods is to evaluate particle tracks with respect to their expected contribution to the sought detector response. Any function providing such an estimate for each point of the phase space is generally known as an *importance map*. For a certain class of variance-reduction algorithms, the provably optimal choice for the importance function^{1,2} is represented by the adjoint flux, i.e. the solution of the adjoint fixed-source Boltzmann equation³.

Description of Work

The goal of this work is to present the development of two new functionalities of the TRIPOLI-4[®] Monte-Carlo particle-transport code⁴, that simplify the construction of a suitable importance map. First, a development version of TRIPOLI-4 has been coupled with the deterministic transport solver IDT⁵. The coupling allows users to seamlessly invoke IDT for the construction of the importance map, without having to convert the TRIPOLI-4 simulation geometry to another format. Multigroup cross sections are automatically condensed and homogenized. The TRIPOLI-4-IDT coupling thus allows users to perform Monte-Carlo calculations based on the CADIS methodology⁶.

Second, we have implemented a new TRIPOLI-4 response function that makes use of the particle tracks generated by a direct (forward) simulation to produce an online estimate of the adjoint flux for a given detector response. The principle has already been described in the literature^{7–9}, but we propose a slightly different, collision-based estimator. The final goal of this work is to use the scored adjoint flux as an importance map for the same simulation.

Results

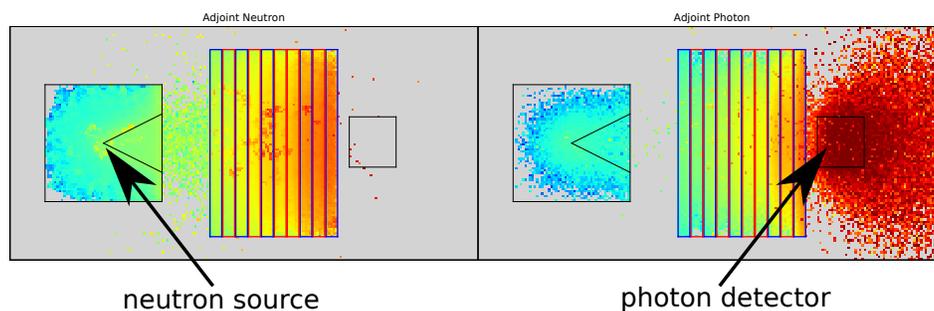


Figure 1. Neutron and photon adjoint flux scored by TRIPOLI-4 for a coupled neutron-photon shielding problem. The plots highlight the lack of information in low-density regions (air, grey).

We have verified that the importance maps calculated by IDT can yield sizeable accelerations compared to TRIPOLI-4's native importance-map-generation module, INIPOND¹⁰. A crucial role is played by the condensation and homogenization algorithms that construct the multi-group cross sections used as an input for IDT.

We also present in Figure 1 the result of an on-line estimation of the importance map for a coupled neutron-photon problem. This particular example is interesting because, in general, neutron-photon problems are difficult to efficiently solve using TRIPOLI-4's native importance-map-generation module. Using our new adjoint-flux response, we can pre-compute the importance map during a first calculation with a simpler, less efficient variance-reduction technique. The resulting adjoint flux can then be injected as an importance map into a new calculation and results in very large speed-up factors.

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