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NARMER-1: a photon point kernel code with build-up factors, MERCURE-6 successor

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Abstract. This paper presents an overview of NARMER-1, the new generation of photon point-kernel code developed by the Reactor Studies and Applied Mathematics Unit (SERMA) at CEA Saclay center. The paper surveys the generic features: programming language, computer platforms, geometry package, sources description, etc. Moreover, specific and recent features are also detailed: exclusion sphere, tetrahedral meshes, parallel operations. Then some points about verification and validation are presented. Finally we present some tools that can help the user for operations like visualization and pre-treatment.

1 Introduction

1.1 History

Starting from the 60s, CEA launched the development of MERCURE, a gamma-ray shielding code using the point-kernel integration formalism. MERCURE-3 was published in 1967 [1]. Later in the 80s, EDF and COGEMA (AREVA) became sponsors of MERCURE for its development and its validation. MERCURE uses a Monte Carlo method and build-up factors. MERCURE-6 has enabled the build-up factor calculation for composed shields by using new algorithms developed by SERMA Reactor Studies and Applied Mathematics Unit (SERMA). Then, the development of NARMER-1 has been launched to integrate both gamma-ray attenuation feature and reflection feature (implemented by MERCURE-6 and NARCISSE-3 respectively).

1.2 The developers team at CEA

NARMER-1, TRIPOLI-4®, APOLLO3®, MENDEL, and GALILEE-1 are developed by SERMA (Service d'Etudes des Réacteurs et de Mathématiques Appliquées), a 80 permanent staff R&D Unit of the Nuclear Energy Division (DEN) of CEA, whose focus is nuclear energy from fission. Depending on the period, between 1 and 3 people are contributing to MERCURE and now to NARMER-1, their activities covering development, integration & architecture, V&V, documentation, user support, distribution and licensing.

1.3 Principles

The point kernel of attenuation has the following classical expression:

$$G(\vec{r},\overrightarrow{r_0},j)=\frac{R(j).B\big(b,j,R(j)\big).e^{-b(j)}}{4.\pi.(\vec{r}-\overrightarrow{r_0})^2}$$

where $\mathrm{b(j)}=\sum_\mathrm{i}\mu_\mathrm{i}(\mathrm{j}).\mathrm{t_i}$ and $\mu_\mathrm{i}(\mathrm{j})$ is the attenuation coefficient while $\mathrm{t_i}$ is the track length in the homogeneous medium *i* for the energy group or energy ray *j*. R(j) stands for the response function and $\mathrm{B(b,j,R(j))}$ is the build-up factor taking the contribution of scattered photons into account.

For the double-layer-shield build-up factor the code uses an empirical formula based on products and ratios of single-layer-shield build-up factors. The formalism then uses iteratively the empirical formula to compute multi-layered-shield build-up factors. Both the empirical formula and the iterative process are improved in the code [2] so that it can solve some difficult cases with an improved accuracy and sturdiness.

2 Generic features

2.1 Programming language, computer platforms

NARMER-1 has been developed in C++ and uses python as the user interface. It is currently developed on Linux system but is maintained and available on both Linux and Windows.

2.2 Geometry package

NARMER-1 comes with the TRIPOLI-4® native geometry package, allowing for both a pure surface-based

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representation, and a combinatorial representation with predefined shapes and Boolean operators (any combination of these two kinds of representations can be adopted).
As well as TRIPOLI-4®, NARMER-1 as has been also made compatible with any geometry developed in the format of the ROOT software (Brun and Rademakers, 1997). This allows the user to directly use (without recompiling) an already built ROOT geometry.
More generally, NARMER-1 may be linked to any third-party geometry module providing an Application Programming Interface for the current particle position and the next intersection in the direction of flight.
Details concerning visualization tools for building and checking the geometry will be provided in Section 4.

2.3 Sources description

Sources are defined with an energetic spectrum and an emitting volume according to a mesh at a given position.

2.3.1 Energy Distribution

Line spectrum can be used as well as group spectrum based on a 195 bounds pre-defined mesh.

2.3.2 Spatial Distribution

Volumic based sources can be described using the following type of meshes : Cartesian, Spherical, Cylindrical, Conic, Toroidal, General Conic, Constant Width Conic, General Cylindrical.

Surface based sources can be described using the following type of meshes : Cartesian, Spherical Shell, Cylindrical Shell, Disk, Conic Shell, Toroidal Shell.

3 Specific or recent capacities

3.1. Exclusion sphere

In order to perform computations for some detectors that can be very close to the emitting volume or inside the emitting volume, it is necessary to avoid a singularity due to the $1/r^2$ factor that can leads to infinite variance. Therefore the code uses an exclusion sphere. The radius of the sphere can be set by the user.

3.2 **Tetrahedral meshes**

For some usage, geometry and emitting volumes are modelled using computer-aided design software allowing easier definition of very complex 3D scenes. In this context the code has the possibility to define tetrahedral meshes for the definition of emitting volumes. Observed performances of the sampling method allow computation in some good conditions.

3.4 Double Energy Angle Differential Albedos

Lacunar media shielding studies can be dealt with albedo concept which is an alternative to the "exact" transport method calculations (SN, Monte Carlo). For multiple reflections on lacunar medium walls, one needs double energy-angle differential albedos because they are function of the incident energy. Reflection feature are a point of interest for EDF sponsor. R&D development and validation studies in this domain are still under progress at SERMA.

3.5 Parallel operations

Complex 3D scenes with a high number of gamma sources and a lot of geometrical volumes to cross can lead to substantial simulation times. Therefore, some developments and validation studies are currently under progress to use multi-threads algorithms.

4 Verification and Validation

Since the NARMER-1 code is attended to be used for radiation protection purposes, verification and validation are crucial issues. Verification is supported in particular by non-regression testing. Excellent results are observed about non-regression results with respect to MERCURE-6. Validation is based on comparison with calculations performed with the TRIPOLI-4 Monte Carlo code as well as with experimental benchmarks.

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