New Features of TRIPOLI-4® V version 10

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INTRODUCTION

TRIPOLI-4®[1] is a three-dimensional and continuous-energy Monte-Carlo transport code developed by the "Service d'Etudes des Réacteurs et de Mathématiques Appliquées" (SERMA), at the CEA Paris-Saclay Center. It is devoted to shielding, reactor physics, criticality safety and nuclear instrumentation.

TRIPOLI-4® has been developed from the mid 1990s in C++. A new version of the code is typically released every two years.

In this paper, we present the new features of TRIPOLI-4® version 10, to be soon released to NEA and RSICC.

TRIPOLI-4® KEY FEATURES [1]

Tracked Particles Format

TRIPOLI-4® is currently able to simulate four kinds of particles (with coupling):

- Neutrons from 20 MeV down to 10^{-5} eV,
- Photons from 50 MeV down to 1 keV,
- Electrons and positrons from 100 MeV down to 1 keV.

Nuclear Data

TRIPOLI-4® uses continuous energy cross sections processed with NJOY from any ENDF-6 format evaluation including JEFF-3, ENDF/B-VII, FENDL-2, JENDL-4. It also uses probability tables from CALENDF in the unresolved resonance range.

Geometry

The code has its own geometry module allowing both surface-based and combinatorial representations. TRIPOLI-4® is also directly compatible with a geometry developed in the ROOT format [2]. Thanks to its modularity, the code may be linked to any third party geometry with limited development effort.

Simulation Modes

Three simulation modes are available in TRIPOLI-4®:

- "Shielding", fixed-source simulation, typically used for radiation protection and shielding analysis.
- "Fixed Sources Criticality", fixed source simulation with treatment of fission events, typically used for subcritical experiments.
- "Criticality", used to compute the fundamental mode and the associated fundamental eigenvalue of the critical Boltzmann equation.

Tallies

A non-exhaustive list of the available tallies includes: volume, surface and point fluxes, surface currents, mesh tallies, reaction rates, deposited energy, built-in KERMA response functions, dose equivalent rate, dpa, gamma spectroscopy and effective multiplication factor

Variance Reduction Techniques

Implicit capture, particles splitting and Russian roulette are available. TRIPOLI-4® also has a special built-in variance reduction module, called INIPOND, based on the Exponential Transform Method, with an automatic pre-calculation of the importance map.

Doppler Broadening of the Elastic Scattering Kernel

For the Doppler broadening of the elastic scattering kernel, the algorithm "Sampling of the Velocity of the Target nucleus" (SVT) is used by default. The "Doppler Broadening Rejection Correction" (DBRC) and the "Weight Correction Method" (WCM) have been implemented in TRIPOLI-4® (from version 9) to overcome the SVT limitations that affect resonant nuclei (such as ^{238}U) typically in the epithermal region.

Verification and Validation

The V&V test base is composed of several parts: elementary verification tests, criticality safety benchmarks, shielding benchmarks, tests concerning parallel operations, tests covering the new features of the code. It includes several ICSBEP and SINBAD benchmarks, as well as proprietary benchmarks from CEA experimental facilities.

[1]TRIPOLI® and TRIPOLI-4® are registered trademarks of CEA, CEA gratefully acknowledges EDF long time support of TRIPOLI-4®

NEW FEATURES OF TRIPOLI-4® VERSION 10

Thick Target Bremsstrahlung for Electromagnetic Shower Simulation

A simplified simulation mode for the electromagnetic shower, similar in essence to the MCNP [3] Thick-Target Bremsstrahlung (TTB) option, has been implemented in TRIPOLI-4® version 10 to speed up coupled photon-electron-positron calculations. When this option is activated, secondary electrons and positrons produced by photon collisions are not transported, but part of their energy is converted into new bremsstrahlung photons.

Analog Neutron or Photon Transport with Analog Fission Sampling

It is already possible with TRIPOLI-4® to perform a fully analog simulation (meaning both collisions and transport between collisions) for neutron and photon transport without fission. The version 10 enables analog fission simulation by sampling a full fission neutron multiplicity distribution using a coupling between TRIPOLI-4® and an external fission model providing fission sampling data (standard nuclear data libraries provide averaged neutron multiplicities only). It permits simulation of time dependent nuclear instrumentation applications needing detailed correlations between fission chains.

Upgrade of the “Replicate” Option

It is possible to perform a two-step calculation using first a global geometry to store the properties (energy, position, direction, weight) of particles crossing a given surface. Then the stored particles are used as surface sources for simulation on a local geometry. The REPLICATE option activates the particle splitting at the second-step. This variance reduction technique permits an improved exploration of the whole phase space, especially when only a limited number of particles has been stored.

Reactor Period Calculation [4]

The asymptotic time behavior of neutron transport can be used in reactor start-up analysis or kinetics studies of nuclear systems. In TRIPOLI-4® version 10, the asymptotic reactor period is calculated as the inverse of the dominant eigenvalue. The algorithm is based on a modified α-k power iteration scheme.

Kinetics Parameters Computing [5]

Kinetics parameters are key to the study of nuclear reactor dynamics and to safety issues in the context of transient or accidental reactor behavior. The Iterated Fission Probability (IFP) method implemented in TRIPOLI-4® version 10 gives access to the adjoint-weighted kinetics parameters: the delayed neutron fraction, the mean generation time and the Rossi Alpha.

Deposited Charge

It is possible to calculate the spectrum of the charge deposited in a given volume by charged particles (electrons and positrons) using the DEPOSITED CHARGE response recently implemented in the version 10. The charge deposition can be used to model signals of sensors irradiated in nuclear reactors, such as Self-Powered Neutron Detectors (SPNDs).

3D Core Fuel-Depletion Calculation

TRIPOLI-4® has been recently extended to cover depletion calculations through a coupling with the MENDEL depletion solver, also developed by SERMA. This coupling solves the Boltzmann-Bateman system of equations which governs the evolution of materials under neutron irradiation. At a given time step, TRIPOLI-4® first computes the reaction rates in each depleted medium. Then, the MENDEL depletion solver calculates the end-of-step nuclide concentration for each region. TRIPOLI-4® version 10 depletion capability is based on a C++ interface accessible via CINT (the C++ interpreter of ROOT [2]), which wraps the methods of both TRIPOLI-4® and MENDEL.

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