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RTS&T-2014 code status

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Abstract

The paper describes the main features of newest version of the RTS&T code system. The RTS&T [1] code (Radiation Transport Simulation and Isotopes Transmutation Calculation) was assigned for detailed Monte Carlo simulation of many particle types (γ, $e^{\pm}$, p, n, $\pi^{\pm}$, $K^{\pm}$, $L_L{}^0$, antinucleons, muons, ions and etc.) transport in a complex 3D geometry's with composite materials in the energy range from a fraction eV to 20 TeV and calculation of particle fluences, radiation field functionals and isotopes transmutation problem as well. A direct using of evaluated nuclear data libraries (ENDF/B-VI.8/VII.1, ROSFOND, JENDL, BROND etc.) to particle transport and isotopes transmutation modeling in low and intermediate energy regions is the general idea of the RTS&T code. It is possible to use the RTS&T code to simulate of reactors, detectors, spacecraft, radiotherapy treatment planning, criticality calculation and radiation safety analysis. The comparison between calculated and measured data is presented.

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Interaction of particles with matter

Photonic processes

In the current version of RTS&T code the following photonic processes types are simulated: photoelectric effect from K,L_I,L_{II},L_{III} atomic shells (the fluorescence x-ray yield and its tracking are also simulated),the Rayleigh and Compton scattering, the pair production and hadronic interactions of photons. The (γ, x) - reactions are simulated in the energy regions of giant dipole resonance, quasi-deuteron effect, isobar production and string excitation at high energies. The EPDL97 evaluated data library of photon-interaction total cross sections, coherent and incoherent scattering form-factors are used in photon transport simulation for the energy range from 10 eV to 100 GeV. Recently, the PENELOPE [2] algorithms are implemented into RTS&T-2014 code to detailed simulation of coupled electron and photon transport for a wide energy range, from a few hundred eV to about 1 GeV.

Electromagnetic processes of charged particles

To simulate the ionization processes induced by the charged particles two different models are provided: the continuous energy loss model with δ-ray generation and restricted Landau-Vavilov fluctuations; the continuous energy loss model without δ-ray production and full fluctuations. The density effect correction to the stopping power of matter has been taken into account. The multiple scattering of charged particles are simulated according to Moliere or Goudsmit–Sounderson theory. Recently, the ICRU recommended data for collision stopping power for electrons, positrons, protons and alpha particles in composite materials were included in current code version. A path length correction for charged particle due to the multiple Coulomb scattering and direct pair production by charged hadrons at high energies are included in the simulation as well.

$e^{\pm}$discretebremsstrahlung process

The discrete bremsstrahlung photon energy is sampled from a Seltzer and Berger [3] differential cross section for electron kinetic energy below 10 GeV and Bethe-Heitler [4] cross section above this value. The angular distribution of the

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emitted photon is sampled according to facilitated form of the double differential cross section. At very high energies the Landau-Pomeranchuk-Migdal effect also has been taken into account.

High-energy hadronic interactions

To simulate of hadron (nucleus)-nucleus inelastic collisions at E $\geq$ 5 GeV a modified [5] FRITIOF 7.02 [6] code can be used. The FRITIOF is a Monte Carlo code that implements the Lund string dynamics model for hadron-hadron, hadron-nucleus and nucleus-nucleus collisions. This code has been completed with a simulation of the nuclear destruction at fast stage of the interaction, with a calculation of the excitation energy of the nuclear residual nuclei and a simulation of the nuclear relaxation stage in the framework of the statistical evaporation model to calculate the characteristics of the inelastic hadron-nucleus and nucleus-nucleus interactions at the energies higher 3 GeV per nucleon. The PSM (Parton String Model) [7], LAQGSM (Los-Alamos Quark-Gluon String Model) [8], DPMJET-III (Dual Parton Model) [9] and JAM (Jet AA Microscopic Transport Code) [10] can be used as an alternative generators in the RTS&T-2014 code. More than 20 decay channels of non-stable particle are available in current code version. The residual nucleus yields due to hA-, γA- and AA-interactions are available too.

Intermediate-energy hadronic interactions

In the RTS&T calculations, the hadron-induced nuclear reaction process in the energy region about 20 MeV to 5 GeV is assumed to be a three-step process of spallation (intranuclear cascade stage), pre-equilibrium decay of residual nucleus and the compound nucleus decay process (evaporation/high-energy fission competition). To calculate the intra-nuclear cascade stage the Dubna-version of intra-nuclear cascade model coupled with the Lindenbaum–Sternheimer isobar model for single- and double-pion production in nucleon-nucleon collisions and single-pion production in pion-nucleon collisions were provided. Recently the addition of multiple-pion channels includes in code package to simulate up to 5 pions emission. The pre-equilibrium stage of nuclear reaction simulation is based on the exciton model. The initial exciton configuration for pre-equilibrium decay is formed in cascade stage of reaction or postulated in general input. The equilibrium stage of reaction (evaporation/fission processes competition) is performed according to the Weisskopf–Ewing statistical theory of particle emission and Bohr and Wheeler or Fong theories of fission. To calculate the quantities determining the total fission width, the Atchison prescriptions are used. The CEM03.03 (Cascade-Exciton Model), JQMD (JAERI Quantum Molecular Dynamics), INCL4.6+abla07 (Liege Intranuclear Cascade model+GSI de-excitation code) and CASCADE04 (IntranuclearCascade+Pre-equilibrium+Equilibrium/Fission) can be used as an alternative generators to simulate of intermediate-energy hadronic interactions in the latest version of the RTS&T code.

A nonstabile particle 2,3-body decays is simulated according to kinematical scheme using the known PDG-branching ratios. Togenerate a multi-particle weighted event according to Lorenz-invariant Fermi phase space the GENBOD (W515) CERNLIB routine is used. Light fragments (d, t, He^3, α etc.) deposit their energy locally or transported according to the general transporting algorithm.

Low-energy hadronic interactions

The RTS&T code uses the continuous-energy nuclear and atomic evaluated data files to simulate of radiation transport and discrete interactions of the particles in the energy range from thermal energy up to 20/150/3000 MeV. In contrast with the MCNP the ENDF-data driven model of the RTS&T code has access evaluated data directly. In current model development all data types provided by ENDF-6 [10] format are taken account in the coupled multi-particle radiation transport modeling. The universal data reading and preparation procedures allows to use of various data library written in the ENDF-6 format (ENDF/B, JENDL, JENDL-HE, FENDL, CENDL, JEF, BROND, LA150, ENDF-HE/VI, IAEA Photonuclear Data Library etc.). The ENDF data pre-processing (linearization, restoration of the resolved resonances, temperature dependent Doppler broadening of the cross sections and checking and correcting of angular distributions

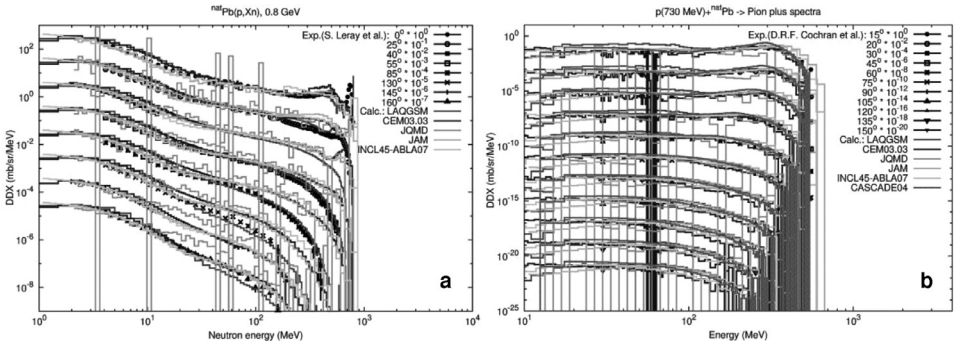

Fig. 1. Comparison of models to the experimental double differential cross sections of neutron and positive pion production in the reaction p (800, 730 MeV)+^{208} Pb.

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