# APPLICATIONS OF COUPLED SCRAPER-RTS&T CODE IN RADIATION THERAPY

I.I. Degtyarev, O.A. Liashenko, I.A. Yazynin, SRC Institute for High Energy Physics, 142284, Protvino, Moscow region, Russia

*Abstract*

The paper describes the main features of the new version of coupled SCRAPER-RTS&T code system. The SCRAPER [1] code performs the numerical simulation of the beam transport in circle accelerators using second-order matrix methods. The RTS&T [2] code (Radiation Transport Simulation and Isotopes Transmutation Calculation) was assigned for detailed Monte Carlo simulation of many particle types ($\gamma$, $e^{\pm}$, 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(HE), JENDL, FENDL, BROND etc.) to particle transport and isotopes transmutation modeling in low and intermediate energy regions is the general idea of RTS&T code. It is possible to use the coupled SCRAPER-RTS&T code to simulate of clinical beam characteristics, for radiotherapy treatment planning and radiation safety analysis. The comparison between calculated and measured data is presented.

## 1 INTRODUCTION

A coupled code was developed for decide some tasks connected with calculation, design and technological development of scraper, radiation shield, extraction, forming, and beam dump systems in circular accelerators and channels. Modeling of a beam movement in electromagnetic fields of the accelerator and the losses distribution is made by the SCRAPER code. The particles transport with allowance of a real interaction processes with substance of elements and shielding components of the accelerator is simulated by the RTS&T code. After we done transport particles which come to vacuum chamber from elements to it's lost. Such way we can done accurate losses distribution of any particles on structure elements and prepare files of energy deposition field to analyze a heating and thermal stresses (using a special utilities for output data converting to ANSYS [3] code input format).

## 2 PARTICLE TRANSPORT IN ACCELERATOR FIELD

In the SCRAPER code the particle moving in electromagnetic fields of accelerator is simulated with using the coordinate transformation matrix method. Each element of structure is presented by six-dimensional matrix, which elements are changing along with the time during the accelerator working regime. Method allows to investigate the particle moving in 3D space under influence of transverse and longitudinal perturbations and synchrotron radiation generation to analyze and technical design the resonance correction, beam extraction, beam scraper, beam forming, beam abort and radiation shield systems. For decide of any tasks we can visual some process occur with beam: Twiss parameters and dispersion (Figure 1), beam boarders, special traces and losses distributions of particles (Figure 2), three-dimensional distributions of particle losses at the elements; particle moving on the phase planes; arrangement of accelerator elements and their apertures and other.

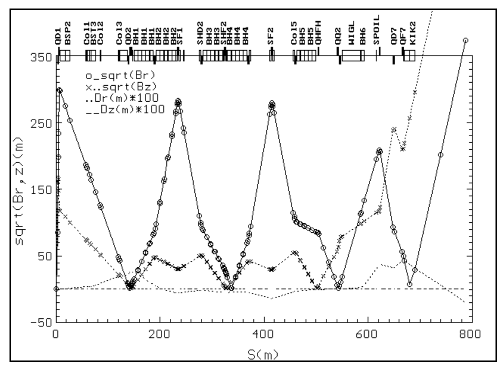



Figure.1: Twiss parameters and dispersion.

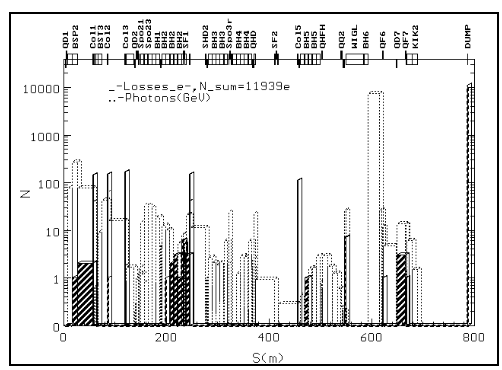



Figure 2: Distribution of leakage particles on an internal surface of collimator.

## 3 PARTICLE INTERACTIONS WITH MATTER

### 3.1 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 (fluorescence x-ray yield and tracking is simulated too); Rayleigh scattering;

Compton scattering; pair production by photons; hadronic interactions of photons. ($\gamma$, x) - reactions in the next energy regions are simulated: giant dipole resonance, quasi-deuteron and isobar production at high energies. The EPDL [4] 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.

### *3.2 Charged particles ionization processes*

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

### *3.3 $e^{\pm}$ discrete bremsstrahlung process*

The discrete bremsstrahlung photon energy is sampled from a Seltzer and Berger [5] differential cross section for electron kinetic energy below 10 GeV and Bethe-Heitler [6] cross section above this value. The angular distribution of the emitted photon is sampled according to facilitated form of the double differential cross section. At very high energies the Landau-Pomeranchuk-Migdal effect is take into account too.

### *3.4 Hadronic processes*

### *3.4.1 High energy hadronic interactions*

In the RTS&T code simulation the hadron-induced nuclear reaction in energy region about 150 MeV to 5 GeV is assumed to be three-step process of spallation: intra-nuclear 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 was provided. Recently the addition of multiple-pion channels includes in code package to simulate up to 5 pions emission. To simulate of hadron(nucleus)-nucleus inelastic collisions at $E \geq 5$ GeV modified [7] FRITIOF 7.02 [8] code can be used. 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 with 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. More then 20 decay channels of non-stable particle are available in current code version. Residual nucleus yields due to hadron interactions are available too.

### *3.4.2 Low-energy nucleons transport*

Nucleons transport in the energy region $10^{-5}$ *eV* $\leq E_n \leq$ 15*0 MeV* in the RTS&T code is based on the *direct* (without the interim libraries compilation) uses of ENDF/B-VI [9] evaluated data library to detailed low-energy nucleon interactions simulation. Universal data reading and preparation procedures allows to use another database written in ENDF/B format. During to execution the linearization, restoration of the resolved resonances, temperature dependent Doppler broaden of the neutron cross sections and checking/correcting of angular distributions and Legendre coefficients for negative values are produced automatically with a help of standard ENDF preprocessing codes LINEAR, RECENT/RECENT-DD, SIGMA1 and LEGEND [10]. Figure 3 shows a comparison of absorbed dose in water slab irradiated by 70 and 100 MeV proton beam [11].

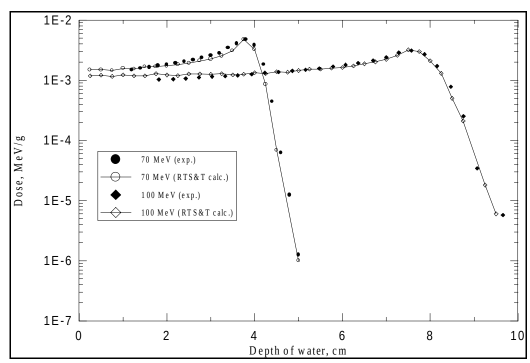



Figure 3: Comparison of doses for 70 and 100 MeV proton beam ($R_x \times R_y$=30×60 mm) incident on water slab.

## 4 RTS&T GEOMETRY DEFINITION

The RTS&T code has an effective geometry definition system provided with a combinatorial method with arbitrary displacements and rotations. Universal geometry module GEOMETRY basically was intended for performing of two functions: 1) detailed description of the spatial geometry and material composition of considered system; 2) localization of the site of transported particle in this system. In framework of combinatorial approach the geometry of any physical object is extreme precisely described through definition of a set of geometrical regions, limited by closed surfaces and filled by homogenous material, and rules of their mutual arrangement. The surface form of each region must correspond to one of the primitive shapes from a fixed set. The new RTS&T geometry module based on the two alternative methods to define of arbitrary 3D configuration. Both recursivial method of coordinate surfaces and quadric surfaces method are provided.

### *4.1 Shape definition*

The recursivial coordinate surface method is used in effective algorithms for analyze whether the considered point is into the region limited by given form of surface. 40 primitive shapes are defined in current code version, some of which is shown in Figure 4. Each of shapes is characterized in size parameters and own local coordinate system. Any optimization algorithms are used for hierarchical enclosure tree analysis. A set of service routines was created for automatic forming of geometry input files for often used configurations, such as a mathematical phantom shown in Figures 5,6.

## 5 RTS&T-CAD-INTERFACE

The problem of a visual presentation of the investigated object's geometry was solved with transformation of the geometry input data to ASCII DXF® (Drawing Interchange Format), designed by the Autodesk company as a standard for exchange by graphic information between AutoCAD® and other applications. Thus the powerful capabilities of CAD-systems make possible not only the visualization of three-dimensional objects with using of an arbitrary rotation in the space and hidden lines but also preparing the designer documentation. RTS&T output files in DXF format will be used for visualization of 3D geometry and material composition of considered system and for showing of particle trajectories (Figures 5,6) and output functionals.

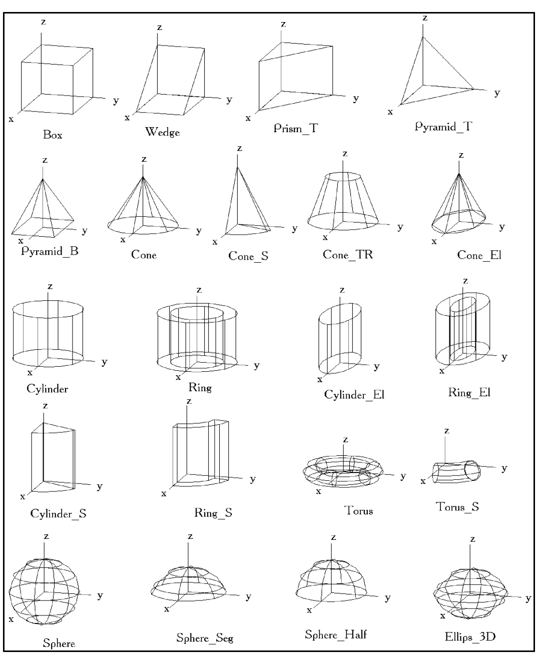
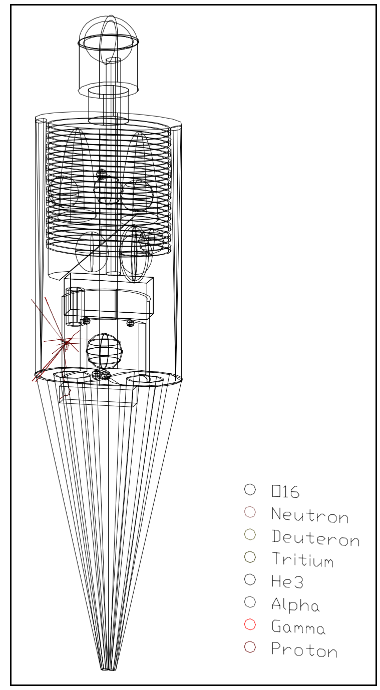
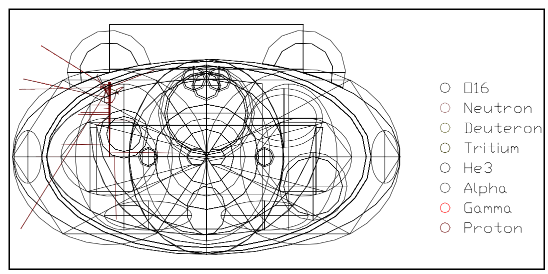



Figure 4: RTS&T Standard set of shapes.




Figures 5,6: Secondary particle tracks in MIRD-2 type mathematical phantom irradiated by the 150 MeV proton beam.

## REFERENCES

[1] I.I.Degtyarev, A.E.Lokhovitsky, Yu.S.Fedotov, I.A.Yazynin. In Proc. of the VI Russian scientific conference on radiation shielding of nuclear installation. Obninsk, Russia, 1994.
[2] A.I.Blokhin, I.I.Degtyarev, A.E.Lokhovitskii, M.A.Maslov and I.A.Yazynin, in Proc. of the SARE-3 Workshop, KEK, Tsukuba, Japan, 1997.
[3] Swanson Analysis System, Inc., SASI/DN – P511:51, Houston, USA, 1994.
[4] D.E.Cullen et al., UCRL-50400 vol.6, LLNL, 1989.
[5] S.M. Seltzer, M.J. Berger, NIM B12 (1985) 95-134.
[6] Y.S. Tsai, Rev. Mod. Phys. 46 (1974) 815.; 49, 815 (1977).
[7] V.V.Uzhinskii. JINR preprint, 1996, E2-96-192.
[8] B.Andersson et al., Nucl. Phys., 1987, v. 281B, p.289.
[9] ENDF-102 Data Formats and procedures for the evaluated nuclear data file ENDF-6. BNL-NCS 44945, July 1990.
[10] Cullen D.E.: IAEA-NDS-39", Rev. 9 (1996).
[11] Yu. G. Budjashov et al., JINR Preprint P9-96-170.