LA-UR-

Approved for public release; distribution is unlimited.

LA-UR- 02-03

c. 1

Title: Recent Developments of the CEM2K and LAQGSM Codes

Author(s): S. G. Mashnik, T-16
K. K. Gudima, Academy of Science of Moldova
A. J. Sierk, T-16

Submitted to: 6th Wold Multi-Conference on Systematics, Cybernetics and Informatics, July 14-18, 2002 Orlando, FL

LOS ALAMOS NATIONAL LABORATORY
3 9338 00864 8239

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Form 836 (8/00)

Summary submitted to the *6th World Multi-Conference on Systematics, Cybernetics and Informatics, July 14–18, 2002, Orlando, Florida, USA*

Recent Developments of the CEM2k and LAQGSM Codes

S. G. Mashnik[1], K. K. Gudima[1,2], and A. J. Sierk[1]
[1] *T-16, Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
[2] *Institute of Applied Physics, Academy of Science of Moldova, Kishinev, MD-2028, Moldova*

Recent developments [1, 2] of the Cascade-Exciton Model (CEM) [3] of nuclear reactions are briefly described. The improved cascade-exciton model as implemented in the code CEM97 [1] differs from the CEM95 version [4] by incorporating new approximations for the elementary cross sections used in the cascade, using more precise values for nuclear masses and pairing energies, using corrected systematics for the level-density parameters, and several other refinements. Algorithms used in many subroutines have been improved, decreasing the computing time by up to a factor of 6 for heavy targets. A number of further recent improvements and changes to CEM97, motivated by new data on isotope production measured at GSI will be presented. This leads us to CEM2k [2], a new version of the CEM code. CEM2k has a longer cascade stage, less preequilibrium emission, and evaporation from more highly excited compound nuclei compared to earlier versions. CEM2k also has other improvements and allows us to better model neutron, radionuclide, and gas production in Accelerator Transmutation of nuclear Wastes (ATW) spallation targets. The improved CEM97 code was recently used both to study fundamental nuclear physics problems like the role of nuclear medium effects in transport of π mesons in nuclei [5] and fission processes at intermediate energies [6], and was incorporated in the well known transport code MCNPX (LANL) to solve applied problems. The CEM95 version [4] of the CEM was incorporated in the MARS (FNAL) and CALOR95 (ORNL) transport codes, and its preequilibrium part was incorporated in many other transport codes like GEANT4 (CERN, see, *e.g.*, [7]), HETC-3STEP (JAERI), HADRON (IHEP, Protvino), CASCADE (JINR, Dubna), SONET (RPCPI, Minsk), etc. The latest version of the CEM code, CEM2k, is still under development. The increased accuracy and predictive power of the code CEM2k will be shown by several examples. Further necessary work will be outlined.

The Los Alamos version of the Quark-Gluon String Model (LAQGSM) was recently implemented in a universal Monte-Carlo code, LAQGSM, for simulating hadron-nucleus and nucleus-nucleus reactions at energies from $\sim$ 20 MeV up to $\sim$ 200 GeV per nucleon [8]. The following physics models are implemented in LAQGSM to simulate the different physics processes involved in various reactions to be calculated by the code: the Dubna intranuclear Cascade Model (DCM), the Quark-Gluon String Model (QGSM), the improved version of the cascade-exciton model contained in the mentioned above code CEM2k, the Fermi break-up model, and the coalescence model.

The quark-gluon string model part of the LAQGSM code is very similar to that in the CERN code GEANT4, described in detail by Nikolai Amelin in [7], as these parts of both codes are based on the same models and were developed by the same authors during their work at JINR, Dubna. Nevertheless there are a number of small differences between these parts of the two codes, like the values of some parameters, the modes of elementary interactions taken into account at the cascade stage, some details in the dynamics of nucleus-nucleus interactions, *etc.* Therefore predictions by the two codes should be similar but not necessarily coincident even for properties with no contribution from preequilibrium and evaporation, which are treated differently by these codes. Example results from the LAQGSM code will be presented and a comparison with predictions by the QGSM, MARS, and FLUKA codes will be given as well.

To describe fission and light-fragment (heavier than ^{4}He) production, both the CEM2k and LAQGSM codes were recently merged with the GEM2 code by Furihata [9]. Some results on fragmentation and fission reactions predicted by these new versions of CEM2k and LAQGSM will be presented and discussed.

This study was supported by the U. S. Department of Energy and by the CRDF Project # MP2-3025.

References

[1] S. G. Mashnik and A. J. Sierk, "Improved Cascade-Exciton Model of Nuclear Reactions," *Proc. of the Fourth Workshop on Simulating Accelerator Radiation Environments (SARE4) September 14–16, 1998, Knoxville, TN, USA* (ORNL, USA, 1999) pp. 29–51; E-print *nucl-th/9812069*; A.J. Sierk and S.G. Mashnik, "Modeling Fission in the Cascade-Exciton Model," *Proc. of the Fourth Workshop on Simulating Accelerator Radiation Environments (SARE4) September 14–16, 1998, Knoxville, TN, USA* (ORNL, USA, 1999) pp. 53–67; E-print *nucl-th/9812070.*

[2] S. G. Mashnik and A. J. Sierk, "Recent Developments of the Cascade-Exciton Model of Nuclear Reactions," *Proc. Int. Conf. on Nuclear Data for Science and Technology (ND2001), October 7–12, Tsukuba, Japan*; E-print *nucl-th/0011064.*

[3] K. K. Gudima, S. G. Mashnik, and V. D. Toneev, Nucl. Phys. **A401**, 329 (1983).

[4] S. G. Mashnik, "User Manual for the Code CEM95," JINR, Dubna (1995); OECD NEA Data Bank, Paris, France (1995);
http://www.nea.fr/abs/html/iaea1247.html; RSIC-PSR-357, Oak Ridge, 1995.

[5] S. G. Mashnik, R. J. Peterson, A. J. Sierk, and M. R. Braunstein, Phys. Rev. C **61**, 034601 (2000).

[6] A. V. Prokofiev, S. G. Mashnik, and A. J. Sierk, Nucl. Sci. Eng., **131**, 78 (1999); R. J. Peterson, S. de Baros, H. Schechter, S. G. Mashnik, A. G. daSilva, and J. C. Suita, Eur. Phys. J., **A10**, 69 (2001).

[7] Nikolai Amelin, "Physics and Algorithms of the Hadronic Monte-Carlo Event Generators. Notes for a Developer," CERN/IT/ASD Report CERN/IT/99/6, Geneva, Switzerland and JINR/LHE, Dubna, Russia; "GEANT4, Users's Documents, Physics Reference Manual," last update 08/04/99: http://wwwinfo.cern.ch/asd/geant4/G4UsersDocuments/UsersGuides/ PhysicsReferenceManual/html/PhysicsReferenceManual.html.

[8] K. K. Gudima, S. G. Mashnik, and A. J. Sierk, "User Manual for the Code LAQGSM," Los Alamos National Laboratory Report LA-UR-01-6804, 2001; http://lib-www.lanl.gov/la-pubs/00818645.pdf.

[9] S. Furihata, Nucl. Instrum. Meth. in Phys. Res. **B171**, 251 (2000); S. Furihata, "The GEM Code—The Generalized Evaporation Model and the Fission Model," *Proc. Int. Conf. on Advanced Monte Carlo for Radiation Physics, Particle Transport Simulation and Applications, October 23–26, 2000, Lisbon, Portugal*, to be publisdhed by Springer Verlag; S. Furihata, K. Niita, S. Meigo, Yu. Ikeda, and F. Maekawa, "The GEM Code—a Simulation Program for the Evaporation and Fission Process of an Excited Nucleus," JAERI-Data/Code 2001-015, March 2001, JAERI, Tokai-mura, Naka-gun, Ibaraki-ken, Japan; private communication on the GEM2 version of GEM from S. Furihata to S. Mashnik, November 2001.