Light Cluster Production in the Cascade Stage of Spallation Reactions

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The Liege Intranuclear Cascade code INCL4 was recently shown to give, when coupled to the ABLA evaporation code[1], and without parameter tuning, very good results, for a large set of data concerning spallation reactions in the 100 MeV to 2 GeV range of incident energies [2]. In this reference, it is argued that the success of this model may come primarily from the self-consistent determination of the stopping time, i.e.the time at which the cascade is stopped and the evaporation code is started. This feature seems to free the model from the introduction of a so-called pre-equilibrium module. However, it is responsible for the lack of production of light clusters of nucleons with energy larger than those typical of evaporation (the so-called pre-equilibrium emission). Although the multiplicities of these kinds of clusters is rather low, their emission may have important implications for spallations sources. Indeed, many of these clusters correspond to gazeous elements, which are liable for modifications of the mechanical properties. It is thus crucial to have accurate predictions for the production of these elements.

Here, we report on a new model for light cluster production in the cascade stage and its implementation in the Liege INC model. The model may be described schematically as follows: (1) When a nucleon appears at the nuclear surface, it is checked whether it can drag a cluster along. (2) A cluster is defined as a group of nucleons sufficiently close to each other in phase space. (3) If the candidate nucleon belongs to a light and a heavier clusters at the same time, the preference for emission is given to the heaviest one. (4) To be emitted, the candidate cluster must, of course, have sufficient energy to overcome the threshold and succeed the usual probabilistic test for crossing the Coulomb barrier. (5) If no cluster can be emitted, the candidate nucleon is emitted. There are two parameters in the model: one is used to determine the location at which the candidate nucleon is tested and the other one defines the closeness criterion on which clusters are built.

This model has been implemented in the numerical code INCL4 and predictions are compared with double differential cross-sections for light cluster (up to alpha's) production, measured by the NESSI group[3] on the p(2.5GeV)+Au systemand and at PSI on the n(540MeV)+Bi and n(540MeV)+Cu systems[4,5]. Good agreement is obtained with a single set of the parameters. The influence of the introduction of the cluster production in the cascade stage on particle multiplicities is also investigated. It is shown that globally more nucleons are ejected in this stage, but free nucleons are emitted less abundantly. Another consequence is the increase of the excitation energy at the end of the cascade stage, which helps to improve the predictions of Ref.[2] for the residue mass spectrum in the fragmentation region.

Finally, the phase space properties of the dynamically constructed clusters are exhibited.

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