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MCNP6 Simulation of Quasi-Monoenergetic ^{7}Li(p,n) Neutron Sources below 150 MeV

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The applicability of MCNP6 to simulate quasi-monoenergetic neutron sources from interactions of proton beams with energies below 150 MeV on thick ^{7}Li targets have been studied. Neutron spectra at zero degrees from a 2-mm ^{7}Li layer backed by a 12-mm carbon beam stopper in an Al flange bombarded with protons of 20, 25, 30, 35, and 40 MeV have been calculated with MCNP6 using the recent Los Alamos data library as well as using the Bertini+Dresner and CEM03.03 event generators. A comparison with the experimental neutron spectra shows that the event generators do not do well in describing such reactions, while MCNP6 using the LANL data library simulates production of neutrons from p + ^{7}Li in good agreement with the measured data.

I.   INTRODUCTION

A real monoenergetic neutron source in the MeV energy region is not feasible, therefore "quasi-monoenergetic" neutron sources are used in different applications. Among such sources, the ones based on the ^{7}Li(p,n) reaction are widespread. Although this reaction was measured many times by different authors at several laboratories (see reviews on available data in Refs. [1, 2, 3]), the measured data do not cover continuously the whole incident proton energy region and the whole kinematics region of secondary neutrons. Therefore evaluated nuclear data libraries are needed for the ^{7}Li(p,n) reaction, to be used in simulations with transport codes of the "quasi-monoenergetic" neutron production from thick lithium targets in every particular application.

In Refs.[1, 2], an ENDF-formated data library for incident protons with energies up to 150 MeV was developed. In those papers, the important ^{7}Li(p,n$_0$) and ^{7}Li(p,n$_1$) reactions were evaluated from the experimental data, with their angular distributions represented using Lengendre polynomial expansions. The decay of the remaining reaction flux was estimated from GNASH nuclear model calculations. This leads to the emission of lower-energy neutrons and other charged particles and gamma-rays from preequilibrium and compound nucleus decay processes. Examples of the use of these data in representative applications by a radiation transport simulation with the code MCNPX [4] are also presented in Refs. [1, 2].

More recently, our data library was used successfully by Simakov et al. in MCNPX simulations to study the activation cross sections on Bi, Au, Co, and Nb targets bombarded with quasi-monoenergetic neutrons produced from the p+^{7}Li reaction at the NPI/Řež cyclotron facility [5]. However, we never tested ourselves the p+^{7}Li data library with the latest Los Alamos Monte Carlo transport code MCNP6 [6]. To fill this gap, here we test the applicability of MCNP6 [6] to simulate quasi-monoenergetic neutron sources from interactions of proton beams with energies below 150 MeV on thick ^{7}Li targets. We used in our study the neutron spectra measured recently by Uwamino et al. from a 2 mm thick ^{7}Li target bombarded with protons of 20, 25, 30, 35, and 40 MeV [7] and took advantages of an MCNPX input file kindly sent to us by Dr. Simakov to simulate the geometry of our problem (see Fig. 1), that we modified later for our MCNP6 needs.
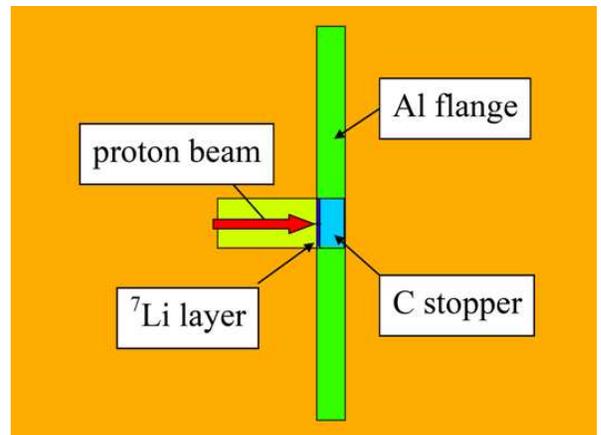

FIG. 1. Geometry model of the target and incident proton beam used in our MCNP6 simulations. The plot was kindly sent to us by Dr. Stanislav Simakov.

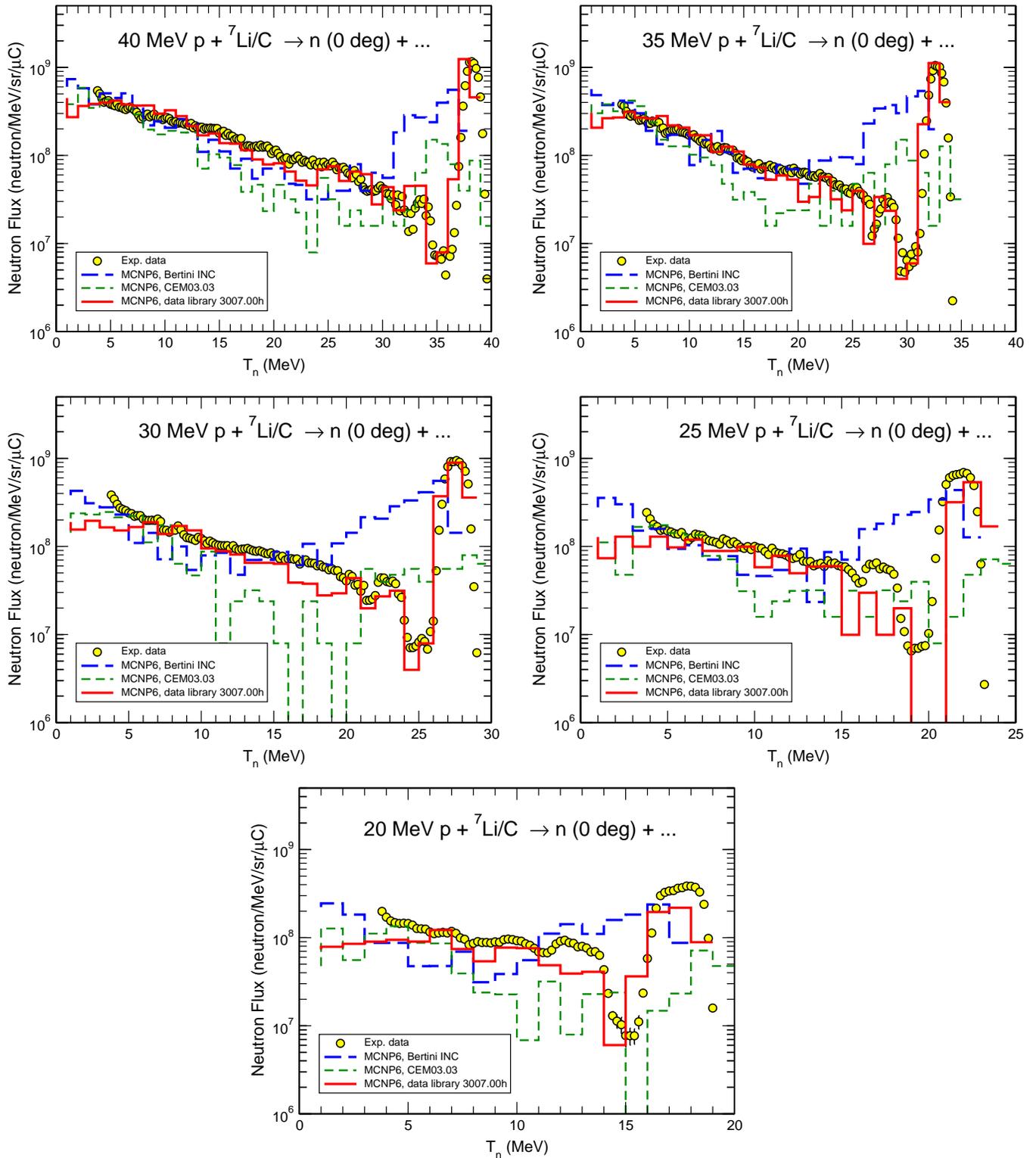* Corresponding author, electronic address: mashnik@lanl.gov

FIG. 2. Comparison of the MCNP6 results (histograms) for neutron spectra from the thick ^{7}Li target (see Fig. 1 for details) bombarded with proton beams of 40, 35, 30, 25, and 20 MeV with the experimental data by Uwamino et al. [7] (solid circles). MCNP6 spectra calculated using the p+^{7}Li data library [1] and, for comparison, with the Bertini+Dresner [8, 9] and CEM03.03 [10] event generators are shown with solid red, blue dashed, and green dashed histograms, as indicated in legends.

II. RESULTS

As a step of MCNP6 Verification and Validation (V&V), we have simulated the neutron spectra from our target consisting of a 2 mm thick ^{7}Li foil, 8 mm thick C beam stopper, and Al holder for the Li foils (see [7] and Fig. 1 for details) running MCNP6 both in a sequential mode and in parallel, with MPI, while using our p+^{7}Li data library. As expected, all results obtained with MCNP6 run with MPI coincide with the ones calculated in a sequential mode. As additional steps of MCNP6 V&V, we have calculated all the studied neutron spectra also using the Bertini+Dresner [8, 9] and CEM03.03 [10] event generators of MCNP6. All our results are presented in Fig. 2. Just as expected for such low energies of incident protons, we can see that neither the Bertini+Dresner [8, 9] nor the newer CEM03.03 [10] event generators can reproduce satisfactorily the measured neutron spectra from our ^{7}Li target: The higher the incident energy the better the agreement, but the quasi-monoenergetic neutron peak is not reproduced well by the models even at 40 MeV. At the same time, all the MCNP6 neutron spectra calculated using the p+^{7}Li data library agree well with the measured data, including in the region of the quasi-monoenergetic neutron peak of interest to our study, for all tested bombarding energies of the proton beam.

III. CONCLUSIONS

We have tested the applicability of MCNP6 to simulate quasi-monoenergetic neutron sources from interactions of proton beams with energies below 150 MeV on thick ^{7}Li targets. Neutron spectra at zero degrees from a 2-mm ^{7}Li layer backed by a 12-mm carbon beam stopper in an Al flange bombarded with protons of 20, 25, 30, 35, and 40 MeV have been calculated with MCNP6 using the recent Los Alamos data library as well as using the Bertini+Dresner and CEM03.03 event generators. Our results show that the models (event generators) do not do well in describing such reactions, while MCNP6 using the LANL data library simulates production of neutrons from p + ^{7}Li in good agreement with the measured data, including the region of the quasi-monoenergetic neutron peak of interest to our work.

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