

EXCITATIONS OF PROJECTILE-LIKE FRAGMENTS  
IN INTERMEDIATE ENERGY HEAVY-ION COLLISIONS

Z. Seres\*, G. Caskey<sup>†</sup>, F. Deák<sup>‡</sup>, A. Galonsky<sup>§</sup>,  
Á. Kiss<sup>‡</sup>, B. Remington<sup>¶</sup>

We report on an aspect of experiments<sup>1,2</sup> performed at the National Superconducting Cyclotron Laboratory measuring fragment-neutron coincidences from reactions  $^{14}\text{N}+^{12}\text{C}$ , Ni and  $^{165}\text{Ho}$  at  $E/A=35$  MeV. The neutrons emitted by projectile-like fragments (PLF) at intermediate energies are kinematically focused around the collinear PLF-neutron geometries giving a large contribution (about 90 %) to the collinear neutron cross section. The contribution of the PLF source was found to be isotope specific and is dominated (up to 40-90 %) by neutrons emitted with discrete energies from one or a few particle-unbound states of the fully accelerated parent fragments for isotopes  $^{6,7}\text{Li}$ ,  $^{7,9,10}\text{Be}$ ,  $^{11}\text{B}$ ,  $^{12}\text{C}$  (ref. 3). The spectra of neutrons emitted with discrete energies in sequential decay can be analysed using the method of relative velocity spectra ( $RV=v_{\text{PLF}}-v_n$ ). The spectra can be interpreted by Monte Carlo calculations<sup>3</sup>.

In the thermodynamic description the excited PLF production is assumed to be emitted from hot nuclear matter in thermal equilibrium. The population of the excited states are determined by a Boltzmann distribution depending on the temperature of the hot nuclear matter. This nuclear temperature can be determined either from the kinetic energy spectra of PLF or from the relative populations of two excited states for the isotopes where more than one particle-unbound states can be identified in the RV spectra (e.g.  $^{13}\text{C}^* \rightarrow ^{12}\text{C}+n$  see ref. 4). As a different method the comparison of the populations of the identified particle-unbound states of Li fragments offers also a possibility to estimate the temperature of nuclear matter supposing that they measure the same temperature. The decay energies are approximately the same ( $E_{6\text{Li}}=205.9$  keV,  $E_{7\text{Li}}=222$  keV), so the ratio of the neutron multiplicities (coincidence cross section from sequential decay divided by inclusive fragment cross section with  $A_{\text{PLF}+1}$ ) for  $^6\text{Li}$  and  $^7\text{Li}$  depends on level parameters (energy, spin, branching ratios), on the excitation energies of the particular particle-unbound states (7.456 and 2.255 MeV, respectively) and the only unknown parameter is the nuclear temperature.

Figure 1 shows the RV spectra in coincidence with  $^6\text{Li}$  and  $^7\text{Li}$  at  $10^\circ$  and  $30^\circ$  for Ho target. The RV spectra are very similar in spite of the rather different average energy loss and dominating reaction mechanisms (quasi-elastic and strongly-damped processes, respectively). To measure the similarity we deduced a nuclear temperature from the relative neutron multiplicities at  $10^\circ$   $T=2.0^{+0.2}_{-0.1}$  MeV and  $30^\circ$   $T=2.3^{+0.4}_{-0.2}$  MeV. These values suggest that the excitation of PLF does not change significantly with the energy loss of the PLF. Furthermore the corresponding RV spectra and inclusive fragment spectra are similar for  $^{12}\text{C}$ , Ni and  $^{165}\text{Ho}$  target nuclei. The rela-

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\* Central Research Institute for Physics, Budapest, Hungary

<sup>†</sup> Donnelly Corporation, Holland, Michigan

<sup>‡</sup> Dept. of Atomic Physics, Eötvös University, Budapest, Hungary

<sup>§</sup> NSCL and Dept. of Physics and Astronomy, MSU, E. Lansing, MI

<sup>¶</sup> Lawrence Livermore Laboratory, California

tive neutron multiplicities are close to unity (table 1) showing that the excitations of the fragments detected at a given angle do not depend on the target masses.

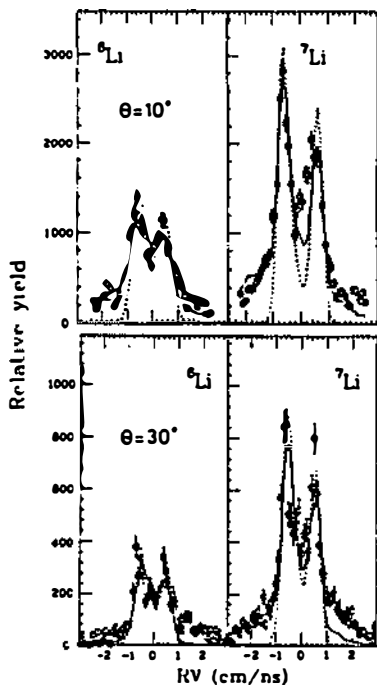


Fig. 1. Collinear PLF-neutron relative velocity spectra for  ${}^6\text{Li}$  and  ${}^7\text{Li}$  fragments detected at  $10^\circ$  and  $30^\circ$  from Ho target. The curves show Monte Carlo fits with (solid line) and without PLF thermal evaporation.

Table 1. Relative neutron multiplicities for Ni and  ${}^{165}\text{Ho}$  targets related to those of  ${}^{12}\text{C}$  target for the identified PLF isotopes.

PLF	Rel. neutron multiplicities	
	M(Ni)/M(C)	M(Ho)/M(C)
${}^6\text{Li}$	$0.79 \pm 0.16$	$0.80 \pm 0.16$
${}^7\text{Li}$	$0.67 \pm 0.47$	$0.73 \pm 0.47$
${}^9\text{Be}$	$1.04 \pm 0.25$	$1.37 \pm 0.34$
${}^{10}\text{B}$	$0.99 \pm 0.2$	$0.89 \pm 0.2$
${}^{11}\text{B}$	$0.98 \pm 0.5$	$1.00 \pm 0.5$
${}^{11}\text{C}$	$0.98 \pm 0.18$	
${}^{12}\text{C}$	$0.92 \pm 0.18$	$0.81 \pm 0.17$

In summary, we found that the excitations of the PLF, i.e. the nuclear temperatures deduced from relative neutron multiplicities are the same for quasi-elastic and strongly-damped processes and do not depend on target masses.

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