EXPERIMENTAL DETERMINATION OF RELATIVE YIELDS AND γ-RAY MULTIPLICITY IN A FUSION-EVAPORATION REACTION IN THE VICINITY OF THE DOUBLY-MAGIC ^{100}Sn*

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Results of a measurement of relative yields and γ-ray multiplicities for nuclei populated in a heavy ion induced fusion–evaporation reaction in the region of ^{100}Sn are presented. The relative cross sections for about 20 reaction products were derived from the intensities of γ rays feeding ground states of respective nuclei, whereas the γ-ray multiplicities were determined by using 30 BaF_2 detectors surrounding the target.

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1. Introduction

Very proton-rich nuclei in the vicinity of the $N = Z = 50$ shell closures are in focus of many experimental and theoretical investigations. Nuclear structure is often studied in this region using heavy-ion fusion–evaporation reactions in which the total cross section is distributed among many reaction channels, corresponding to different numbers of protons, α particles and neutrons emitted from the compound nucleus. Although estimates of the production cross sections are sometimes obtained as a by-product of studies of excited states of nuclei in this region, in general information on the cross sections is very limited. The available data are usually restricted to selected evaporation channels, measured in thick target experiments [1] (*i.e.* with the effective beam energy not well defined), seldom available for more then one

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beam energy, and often affected by the trigger conditions. More systematic information on the cross sections is needed for understanding the fusion–evaporation process in this exotic region, and for optimizing conditions of experiments aiming at observation of more and more proton-rich nuclei.

Information on the γ-ray multiplicity (M_γ) in this kind of experiments is even more scarce. In general, γ-ray multiplicity measurements are widely used to obtain information on the angular momentum involved in different kind of nuclear reactions and provide important information on the quasi-continuum deexcitation of the evaporation residues. There is no, however, such data available for nuclei situated very close to the proton drip line.

2. Experiment

The experiment was performed at the Tandem Accelerator Laboratory at Risø, Denmark with the NORDBALL detector array [2,3]. Beam of ^{58}Ni was hitting a thin ^{50}Cr target (0.25 mg/cm^2), enriched to 96.8%, backed by 23 mg/cm^2 of ^{197}Au, leading to the compound nucleus ^{108}Te. Data were collected at five beam energies: 201, 216, 231, 246 and 261 MeV, corresponding to compound nucleus excitation energy: 48, 55, 62, 69 and 76 MeV, respectively. The energy loss of beam particles traversing the ^{50}Cr target was about 6 MeV (similar at each of the 5 bombarding energies). Events were accepted by the data acquisition system if at least one Compton suppressed γ-ray was detected in one of the 15 Ge detectors and one γ-ray in the BaF_2 array surrounding the target. Other details of the experimental setup are given in Ref. [4].

3. Data analysis and results

3.1. Relative yields

The relative yields of residual nuclei produced in the reaction were deduced from intensities of γ-ray lines feeding ground states of respective nuclei. It was necessary to use the γ–γ coincidence data for this purpose in order to obtain sufficiently clean γ-ray peaks (see also Ref. [4]). The measured yields were thus affected by the effective trigger condition that at least one γ-ray was detected in the BaF_2 array and two in the Ge detectors. The influence of this condition on the registration probability was estimated by using the experimental γ-ray multiplicity distributions (see below).

The relative yields measured at different beam energies were normalized to the total fusion–evaporation cross section calculated by statistical codes: 189 mb, 393 mb, 566 mb, 698 mb and 727 mb, for the five beam energies, respectively (the average values given by three codes: HIVAP, EVAPOR, CASCADE). The results are collected in Table I. Work on comparison of the

TABLE I

Relative fusion–evaporation yields measured in this work, normalized to the total calculated cross section (in mb), given for five beam energies (in MeV).

$E_{\rm beam}$	52	53	54	55	56	N/Z
					^{108}Te (CN)	52
						51
				^{105}Sn $2pn$		
201				—		
216				13.1 ± 1.6		
231				9.6 ± 1.4		50
246				5.2 ± 1.5		
261				—		
			^{103}In αp	^{104}In $3pn$	^{105}In $3p$	
201			—	—	52.6±4.0	
216			—	37.1±3.3	64.3±4.1	
231			—	43.5±3.3	67.7±4.2	49
246			7.5±1.4	23.5±3.3	37.4±2.8	
261			13.9±2.5	18.3±2.7	10.1±3.6	
		^{101}Cd $\alpha 2pn$	^{102}Cd $\alpha 2p$	^{103}Cd $4pn$	^{104}Cd $4p$	
201		3.6±1.5	36.6±3.9	—	88.6±6.7	
216		15.5±2.3	33.1±3.2	11.2±1.6	160.9±9.2	
231		11.4±1.5	37.1±3.6	41.5±3.0	231.0±10.6	48
246		19.4±1.7	30.5±2.7	119.6±6.7	176.8±7.3	
261		16.1±2.3	32.6±2.9	127.3±7.2	57.8±4.0	
	^{99}Ag $2\alpha p$	^{100}Ag $\alpha 3pn$	^{101}Ag $\alpha 3p$	^{102}Ag $5pn$	^{103}Ag $5p$	
201	—	—	7.8±2.2	—	—	
216	—	—	23.5±4.0	—	8.3±2.1	
231	—	9.3±1.0	58.2±3.8	—	14.6±3.7	47
246	2.6±1.2	19.8±1.7	68.8±5.1	5.2±1.4	37.6±4.0	
261	22.9±2.4	11.8±1.1	99.4±7.0	23.8±3.5	58.6±5.0	
	^{98}Pd $2\alpha 2p$	^{99}Pd $\alpha 4pn$	^{100}Pd $\alpha 4p$			
201	—	—	—			
216	11.0±3.1	—	7.3±3.6			
231	9.5±2.1	—	24.5±4.3			46
246	43.2±3.8	2.6±1.2	78.9±5.2			
261	46.7±3.6	22.9±2.4	143.2±7.1			
	^{97}Rh $2\alpha 3p$					
201	—					
216	—					
231	—					45
246	14.1±2.4					
261	39.1±3.5					

experimental results and results of statistical calculations is in progress. Very significant difficulties are so far encountered in reproducing the experimental yields.

3.2. γ-ray multiplicity

The γ-ray multiplicity for individual nuclei was determined by using 30 BaF_2 detectors surrounding the target. The number of emitted γ rays was estimated from the number of active BaF_2 detectors by using the multiplicity calibration of BaF_2 detectors obtained with the ^{207}Bi source [5]. The results are presented in Fig. 1. A natural dependence of the γ-ray multiplicity on the beam energy (and thus the excitation energy) is observed. It is also expected that the γ-ray multiplicity should drop with the number of

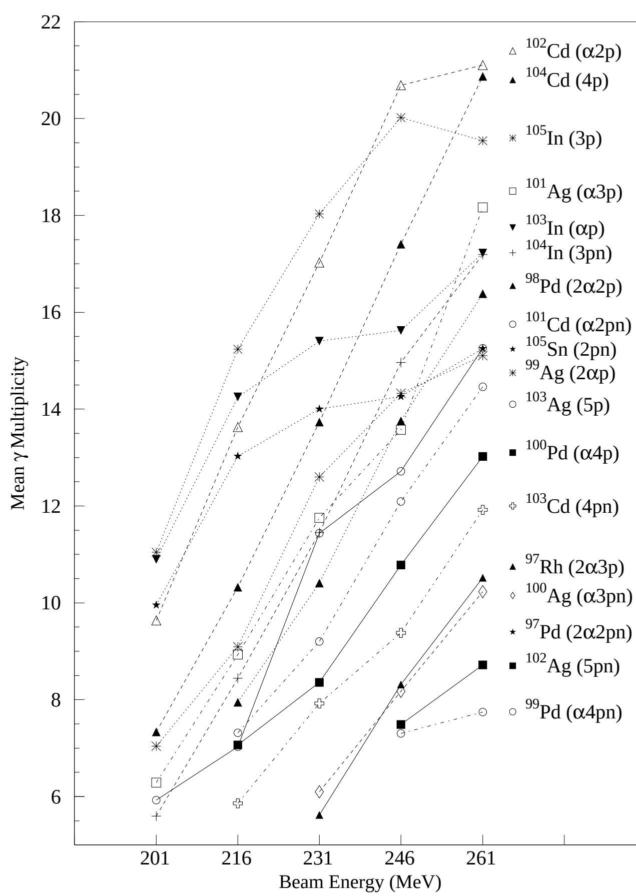

Fig. 1. Experimental mean γ-ray multiplicity as a function of the beam energy.

emitted particles and that the emission of α particles removes more angular momentum than the emission of protons and neutrons, and thus leads to a lower γ-ray multiplicity. While the dependence of the γ-ray multiplicity on the number of emitted particles certainly holds, a surprising lowering of the γ-ray multiplicity is observed for the evaporation channels which include a neutron. This is most easily seen when comparing pairs of the evaporation channels with the same number of evaporated particles such as $4p$ *vs.* $3pn$ and $3p$ *vs.* $2pn$. The proton only channels lead to higher γ-ray multiplicity, and for the 2 above mentioned pairs the difference of the γ-ray multiplicity ranges from 1.7 to 3.6 and from 1.1 to 5.8, respectively, increasing with the beam energy. A similar comparison for the channels which involve an α particle shows that the influence of the neutron emission on γ-ray multiplicity is at least as large as of the α emission. Note that a large γ-ray multiplicity measured for the $\alpha 2p$ evaporation channel leading to ^{102}Cd is especially surprising, as the existence of a 50 ns isomeric 8^+ state in this nucleus significantly lowers the average number of prompt γ rays available for the detection.

The observations discussed above might suggest that the fusion–evaporation process in this very neutron deficient region differs from the classical picture, and is not yet fully understood. A similar hyphotesis was formulated in connection to the recent reports on populating high spin states in ^{111,113}I via the αp reaction, at a very low energy above the Coulomb barrier [6].

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