PROGRESS WITH THE STATISTICAL GIANT DIPOLE RESONANCE DECAY EXPERIMENT AT THE WARSAW CYCLOTRON * **

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The giant dipole resonance (GDR) in highly excited ^{70}Se populated in a heavy-ion fusion reaction ^{12}C + ^{58}Ni at 47.5 MeV beam energy from the Warsaw Cyclotron has been studied. High-energy γ-ray spectra have been measured with the JANOSIK set-up consisting of a large NaI(Tl) spectrometer in coincidence with the 32 elements multiplicity filter. The first experimental results and further plans are discussed. A brief description of the JANOSIK set-up is given.

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1. Introduction

In recent years, a number of experiments studying the statistical giant dipole resonance (GDR) decay of highly excited nuclei have shown that studies of this kind yield important information about nuclear properties at finite temperature and, possibly, about dynamical effects in fusion/fission reactions [1–4]. We plan to continue these studies at the Warsaw Cyclotron at beam energies of 3–10 MeV/u with the new experimental set-up for high-energy γ-ray studies. Below we present a brief description of this set-up,

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called JANOSIK, as well as the first experimental results obtained for the $^{12}C + ^{58}Ni$ reaction.

2. Experimental details

The experiment was performed using the ^{12}C beam of 47.5 MeV energy from the U-200 Warsaw Cyclotron. Self-supporting rolled metalic Ni targets with thickness of 1.5 and 2.0 mg/cm^2 were used. The isotopic enrichment in ^{58}Ni was 99.89 %.

Gamma-rays from the decay of $^{70}Se^*$ were detected in a ϕ25.4 cm $\times$ 29 cm NaI(Tl) crystal at a lab angle $\theta_{lab} = 90°$ with respect to the beam axis. The crystal was viewed by four ϕ7.5 cm PM tubes and surrounded by active and passive shields. This NaI(Tl) detector, which was prepared for some other purposes [5] has a ϕ8.1 cm $\times$ 17.8 cm hole, parallel to the symmetry axis of the cylinder and placed above the axis. Another small NaI crystal was inserted into this hole. Signals from this detector and the four large PM tubes were summed during the experiment. The influence of this insert on the response function was tested with radioactive sources as well as with the GEANT code.

The anticoincidence shield made by BICRON of 10 cm thick BC-412 plastic scintillator slabs surrounded the NaI(Tl) crystal to reject cosmic rays and events in which a significant amount of energy from a photon-electron shower escapes from the crystal. The shield consists of a cuboidal tunnel viewed by four ϕ7.5 cm PM tubes and a front plate viewed by two PM tubes. The plastic walls were wraped into reflective foil and black vinyl, separately for each segment. A 2.25 cm space between the central crystal and the plastic shield was filled with ^6LiH to absorb neutrons. Assembled together NaI(Tl) and plastic detectors were housed in a low activity lead shield formed by a 10 cm thick tunnel and covered on the front by a 12 cm thick wall. The front lead shield has a rectangular opening where lead pieces can be inserted to collimate γ-rays produced in the target. The idea of the shields is well known. They lower the background, especially of the cosmic-rays, which is very important in this kind of small cross-section studies; they also improve the energy resolution of the spectrometer.

The response function for 30 MeV γ-rays (Fig. 1) was evaluated with the GEANT code in the single mode and in anticoincidence with the plastic scintillator shields. These shields are very important in rejecting events with significant energy leakage from the NaI(Tl) crystal.

The entire spectrometer assembly weighs about 2500 kg. It is supported by a carriage which can be rotated around the target axis running on the bent, nearly semicircular track. The detector can also be moved radially by a screw arrangement in the 60 cm to 120 cm range of the distance from the

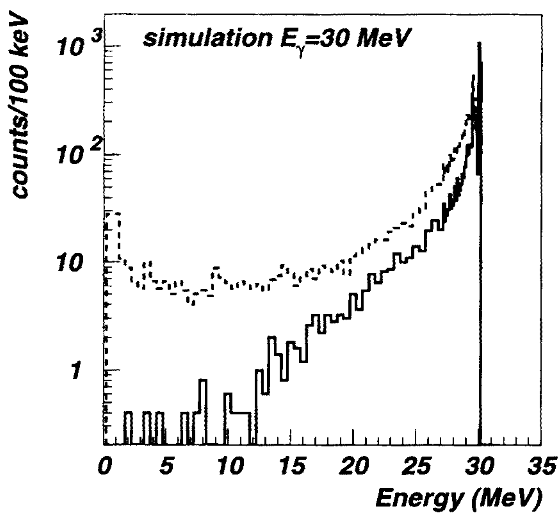

Fig. 1. The response function of the ϕ25.4 cm$\times$29 cm NaI(Tl) detector in the single mode and in anticoincidence with the plastic scintillator shields calculated with the GEANT code for 30 MeV γ-ray.

target to the crystal face. The angular range with the system positioned at a distance of 80 cm from the target to the NaI face is 40° to 140° with respect to the beam axis.

In order to control the NaI(Tl) gain stability a blue LED shined light pulses into a bundle of five optical fibers, four of which illuminated the NaI phototubes, while the fifth the PIN diode monitor detector. Under normal operation the LED amplitude is adjusted so that the light injected into the four phototubes produces a pulse, equivalent to γ-ray with E_γ = 40-100 MeV. The height of this pulse is monitored in the γ-ray spectrum and may be compared with the position of the PIN diode signal which should be very stable.

The beam line, the target chamber and a Faraday cup placed 6.5 m behind the target have been aligned before experiment to avoid that beam hits any material near the detector. In order to control stability of the beam tuning and to define the beam axis a set of two Ta diaphragms of ϕ1 cm and ϕ0.5 cm, distant by 36 cm, was placed 72 cm upstream of the target. During the experiment the beam was tuned for the minimum current on the downstream diaphragm and dumped 6.5 m behind the target in a pitch and lead housing. All beam pipes behind the target chamber are lined inside with 2 mm lead sheet. It helps to avoid background radiation other than from the target itself. The beam current was collected by a Faraday cup and measured by integrator. In order to enhance efficiency of the charge collection an additional quadrupole lense was placed 168 cm downstream from the target chamber.

The system is equipped with a multiplicity filter to record the low energy photons (mainly E2). The filter consists of 32 radially mounted cylindrical scintillation detectors surrounding the target chamber: 12 BaF_2 (each of $\phi 5$ cm $\times$ 5 cm scintillator) and 20 NaI(Tl)'s (8 scintillators of $\phi 7.5$ cm $\times$ 7.5 cm and 12 scintillators of $\phi 5$ cm $\times$ 6.3 cm). With a 16 cm distance between the front of the detectors and the target the efficiency for 1.17 MeV γ-rays from a ^{60}Co source is around 10%.

Six parameters have been recorded during the experiment by 6 ADCs: the multiplicity of BaF_2 detectors (MULT1), the multiplicity of small NaI(Tl) detectors (MULT2), the energy of the high-energy γ-ray (above 3 MeV threshold) recorded by the large NaI(Tl) detector (NaI), the time between the START signal from the large NaI(Tl) detecting high-energy γ-ray and the STOP signal from the multiplicity filter (Time), the bit pattern indicating presence or absence of the coincidence parameters (beam, signal from the plastic anticoincidence shield and signal from the antipileup system) (Coinc) and the PIN signal (PIN). Data have been recorded in an event by event mode. Inclusive spectra of the six parameters recorded during the ^{12}C + ^{58}Ni experiment are shown in Fig. 2. Coincidence spectra with the requirements on the presence of the beam, plastic scintillator signal and signal from the antipileup system have been viewed on-line and sorted for analysis off-line. The energy spectra with those requirements (Fig. 3) have allowed an instant test of the cosmic-ray rejection efficiency, which was determined from the spectra measured without the beam to be 92–96 % depending on the plastic threshold. Because of some problems with plastic PM's the in-beam rejection efficiency in this experiment was only 86 % what was reflected in the quality of the high-energy part of the in-beam γ-ray spectra (see also Fig. 5 and 6). The cosmic-ray rejection efficiency for the large NaI(Tl) spectrometer has been also calculated with the GEANT code giving a value of 98 % on the average.

The $n-\gamma$ discrimination has been achieved by the standard time of flight (TOF) technique. The NaI(Tl) detector was placed at a distance of 83 cm between the crystal face and the target. The TOF spectrum shows a sharp peak due to γ-rays and a broad peak corresponding to neutrons of different energies (Fig. 4). The time resolution of the set-up was 4.5 ns.

The whole set-up has been tested in the ^{12}C + ^{27}Al experiment at the average energy of $\langle E_p \rangle = 45.7$ MeV, corresponding to the beam energy of $E_p = 47.5$ MeV. The cross-section measured at $\theta_{\rm lab} = 90°$ with JANOSIK has been compared with the data for this reaction measured at $< E_p >=$ 48.2 MeV in Seattle [6] with a similar, very well tested set-up (Fig. 5).

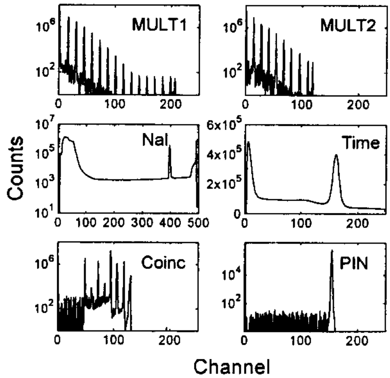

Fig. 2. Inclusive spectra of the six parameters (see text) recorded during the ^{12}C + ^{58}Ni experiment.

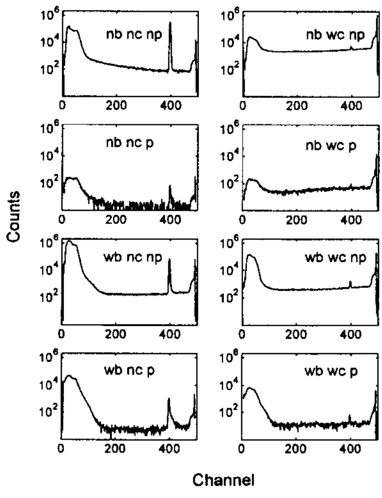

Fig. 3. Coincidence energy spectra with the requirements on the presence of the beam (nb — no beam, wb — with beam), plastic scintillator signal (nc — no signal, wc — with signal) and signal from the antipileup system (np — no signal, p — with signal) for the ^{12}C + ^{58}Ni experiment.

The data (assuming very close response functions for both NaI detectors) are in good agreement up to $E_\gamma = 22$ MeV. At higher energies, in the spectrum measured with JANOSIK, the cosmic-ray background distorted the spectrum shape. This is the result of the not larger then 86% efficiency for the cosmic-ray rejection in-beam.

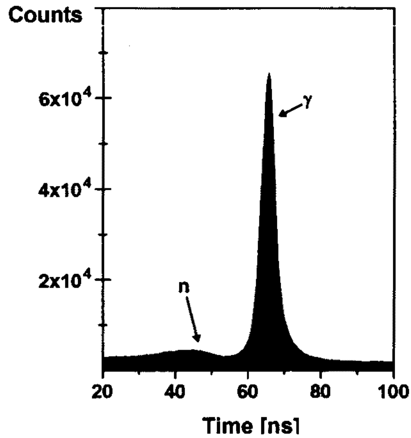

Fig. 4. Time of flight spectrum measured in $^{12}C + ^{58}Ni$ reaction at 47.5 MeV with the NaI(Tl) detector placed at $\theta_{lab} = 90°$, 83 cm from the target.

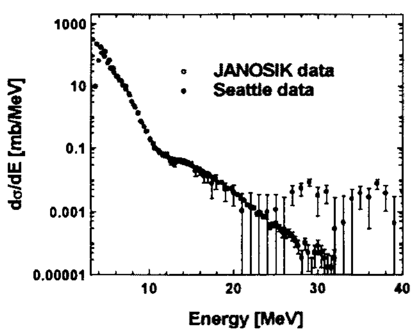

Fig. 5. Comparison of the γ-ray spectrum for the reaction $^{12}C + ^{27}Al$ at $E_p = 47.5$ MeV measured at $\theta_{\rm lab} = 90°$ with JANOSIK set-up and the data for this reaction measured at $< E_p >= 48.2$ MeV in Seattle [6].

3. Results of the GDR studies in hot ^{70}Se nuclei

The low energy structure for the ^{70}Se nucleus resembles the pattern characteristic for vibrational nuclei, suggesting a spherical shape. However, the ^{76}Se nucleus is clearly showing the deformation in the ground-state [7]. Thus with increasing angular momentum the ^{70}Se nucleus is expected to become oblate, when ^{76}Se nucleus being prolate should also change its deformation.

The GDR built on the ^{70}Se ground state has not been studied, but in ^{70}Ge the $T_<$ GDR component has been localized in (γ,n) reaction at 16.4 MeV, in ^{76}Se at 15 MeV [7]. The GDR widths are 5.8±.3 and 8.8±.3 MeV for ^{72}Se and ^{76}Se, respectively [7].

We are planning to study GDR in ^{70}Se and ^{76}Se isotopes at a few excitation energies in the range of 40–100 MeV and at several values of angular momentum in order to examine the shape evolution of those nuclei. Reactions planned to study are: ^{12}C + ^{58}Ni $\rightarrow^{70}$Se and ^{12}C + ^{64}Ni $\rightarrow^{76}$Se. Further plan includes studies at around 11 MeV/u to examine bremsstrahlung γ-ray emission, as discussed in [8].

We have measured high-energy γ-ray spectra from the ^{12}C + ^{58}Ni reaction at 47.5 MeV beam energy. The ^{70}Se* compound nuclei have been populated at the initial excitation energy of E_x = 39 MeV and average spin 13.5 $\hbar$. The measured γ-ray spectrum $\sigma_\gamma^{\exp}(E_\gamma)$ from the statistical decay of the ^{70}Se is shown in Fig. 6 (top) together with the least-square fitted CASCADE calculations. The GDR parameters extracted from the fits with the level density in the Reisdorf approach and fitting range of E_γ = 11–20 MeV are: S =0.66±.08, $E_{\rm GDR}$ =16.6±.4 MeV and Γ =7.5±.8 MeV. The resonance energy is in agreement with systematics. Fig. 6 (bottom) shows

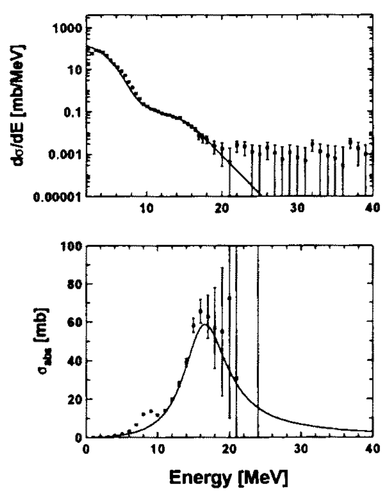

Fig. 6. Top row: γ-ray spectrum for the reaction ^{12}C + ^{58}Ni at E_p = 47.5 MeV measured at a lab angle of 90° with JANOSIK set-up (points with errors) and CASCADE fits to the data (solid line). Bottom row: absorption cross section $\sigma_{\rm abs}(E_\gamma)$ calculated with GDR parameters given in the text (solid line) and $\sigma_{\rm abs}^{\exp}(E_\gamma)$ (data points).

the GDR absorption cross section $\sigma_{\rm abs}(E_\gamma)$ determined from the CASCADE fits, together with points defined as $\sigma^{\rm exp}_{\rm abs}(E_\gamma) = \sigma^{\rm exp}_\gamma(E_\gamma)\sigma_{\rm abs}(E_\gamma)/\sigma_\gamma(E_\gamma)$.

Low statistics in this first experiment were partially due to the 10% efficiency of the multiplicity filter producing STOP signal for TAC. In the future experiment we plan to use the cyclotron RF signal as a TAC STOP. This, together with an increase in the beam intensity and an increased opening of the NaI(Tl) detector, should allow to measure angular distributions in a reasonable time.

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