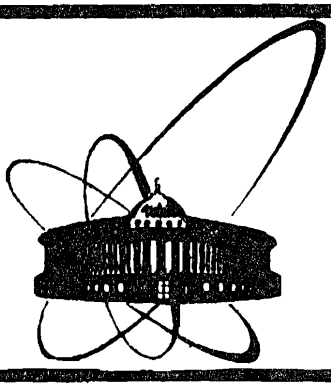

Объединенный
институт
ядерных
исследований
дубна

E7-86-457

V.V.Kamanin, A.Kugler, Yu.E.Penionzhkevich,
Yu.G.Sobolev, A.S.Fomichev, I.David

COMPARISON OF THE YIELDS OF HIGH-ENERGY GAMMA-RAYS WITH $E_\gamma \geq 10$ MeV MEASURED IN THE REACTIONS $^{nat}Sn + ^{40}Ar$ AND $^{68}Zn + ^{64}Zn$

Submitted to "Zeitschrift für Physik"

1986

Introduction

The numerous observations of the emission of high-energy neutrons and light charged particles in heavy-ion reactions renewed the interest of physicists in the study of the preequilibrium processes in reactions between complex nuclei [1]. The possibility of the emission of high-energy ($E_\gamma \geq 10$ MeV) gamma-rays at the first stages of the heavy-ion fusion reactions was discussed in the recent papers [2-4]. The "cooling" of the evaporation spectrum of light particles (alphas, protons, neutrons) gated by high-energy gamma-rays as compared with the inclusive spectrum was reported both in the study of the $^{58}Ni+^{16}O$ (76 MeV) reaction [2] and in the study of the $^{159}Tb+^{12}C$ (100 MeV) reaction [3]. The enhancement of the 1n and 2n evaporation channels as compared with the predictions based on the statistical theory was observed in the $^{87}Ru+^{65}Cu \longrightarrow ^{148}Dy$ reaction [4]. The authors of the above-mentioned papers did not make any definite conclusions, but it is clear that the assumption of preequilibrium emission of high-energy gamma-rays can explain the experimental data.

At the same time there have been observed by many authors [5-8] broad "shoulders" ("bumps") in the gamma-spectra at energies $E_\gamma \geq 10$ MeV in heavy ion reactions. These shoulders were associated mainly with the decay of the giant dipole isovector resonance (GDR) built upon the high excitation states of the compound nucleus. The registered gamma-rays were gated by a signal from big scintillator gamma detectors placed near the target and triggered mainly by the cascades of soft ($E_\gamma \approx 1$ MeV) gamma-rays corresponding to the last stages of the decay of excited reaction products. But it is clear that the products of deep inelastic collisions, which play an important role in heavy-ion reactions [9] cannot be distinguished from the compound nuclei by this "gamma-start" method. Therefore we gated high-energy gamma-rays by a signal from the fission fragments detector in our previous study of the $^{192}Os+^{15}N$, $^{181}Ta+^{22}Ne$ and $^{159}Tb+^{40}Ar$ reactions [10]. The masses of the Bi compound nuclei formed in the reported fusion reactions differed by several units only, but the spectra of high-energy gamma-rays observed in the fusion-fission channel were very different. This entry channel effect may indicate the preequilibrium emission of high-energy gamma-rays.

The present paper is devoted to a more thorough study of the role of the main reaction channels in the emission of high-energy gamma-rays in the $^{nat}Sn+^{40}Ar$ (E_{Ar}=300 MeV) and $^{68}Zn+^{64}Zn$ (E_{Zn}=290 MeV) reactions. The reaction products were identified by means of a KX-ray

detector. The yields of KX-rays, which correspond to a broad range of Z, were determined as a function of the energy of the gating gamma-ray up to a gamma-ray energy E_γ =20 MeV. We report the spectrum of gamma-rays in the range of E_γ =(4-20)MeV gated by KX-rays of evaporation residues. The anisotropy of gamma-ray emission was determined in a wide range of E_γ for the $^{nat}Sn+^{40}Ar$ reaction.

Experiment

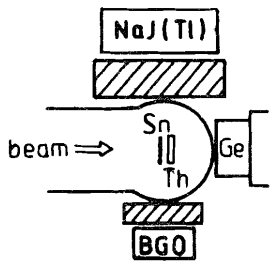

Fig.1. Experimental setup.

The principal design of the experiment is demonstrated in fig.1. The beam of heavy ions from the U-300 cyclotron of the Laboratory of Nuclear Reactions of JINR hit targets of 15 mg/cm^2 thickness, which were backed by a Th metallic foil of 47 mg/cm^2 thickness. The beam was stopped entirely in the target backing. The KX-ray intrinsic Ge-detector was placed behind the target and its efficiency was 5% for KX-ray energies E_{KX}=(25-80)keV. The corresponding energy resolution FWHM was equal to 600 eV. The high-energy gamma-ray detectors of a Ø 75 x 25 mm BGO scintillator and of a Ø 150 x 100 mm NaI(Tl) scintillator were placed perpendicularly to the beam direction at distances of 100 mm and 200 mm from the target. Discriminator levels were set such that only gamma-rays with $E_\gamma \geq 4$ MeV were accepted. The experimental setup was described in more detail elsewhere /10/.

The angular anisotropy of high-energy gamma-rays were determined in the following experimental setup. Two high-energy gamma-ray BGO detectors were placed at angles of 90 and 0 degrees to the beam direction. The trigger gamma-ray detector of the Ø 63 x 63 mm NaI(Tl) scintillator was placed perpendicularly both to the beam direction and to the plane determined by the two BGO detectors at a distance of 25 mm from the target. In these experiments the ^{nat}Sn target of 180 mg/cm^2 thickness was used.

Results

The spectrum of gamma transitions in the $^{nat}Sn+^{40}Ar$ reaction, which were detected in coincidence with a signal from the KX-ray detector corresponding to the broad range of energies E_{KX}=(25-400)keV, is demonstrated in fig.2. The low-energy part of the spectrum is composed mainly of statistical transitions which cool the compound nucleus

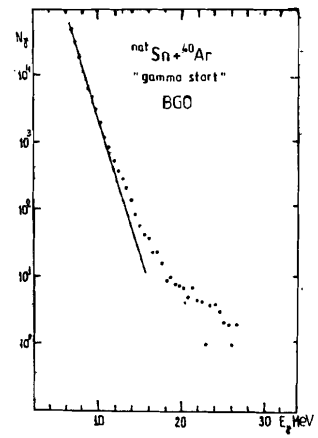

Fig.2. Spectrum of gamma-rays gated by registration of soft gamma-rays of E_{KX}=(25-400) keV.

at the last stages of the evaporation cascade /5/. This region of the spectrum can be roughly approximated by the function $\exp(-E_\gamma/T_{eff})$, $T_{eff} \approx 1.1$ MeV. Above this region the spectrum significantly deviates from the exponential fall and has the form of a broad peak convoluted with an exponentially falling function. Newton et al./6/ observed a similar spectrum in the reaction $^{124}Sn+^{40}Ar$ by using the "gamma-start" method. The high-energy part of the spectrum had to consist mainly of transitions due to the statistical decay of GDR's of the compound nucleus, as the authors of previous papers /5-8/ had assumed. We have gated gamma transitions by KX-rays which correspond to Z not too far from the Z of the compound nucleus (see fig.3) to determine the spectrum of gamma-rays due to the fusion channel of the reaction. The resulting spectra of gamma transitions detected in BGO and NaI(Tl) detectors are shown in fig.4. These spectra differ singificantly at energy $E_\gamma \geq 10$ MeV from the spectrum of gamma transitions gated by soft gamma-rays (fig.3). Because of the existence of the pronounced minimum at $E_\gamma \approx 16$ MeV in these spectra, we have divided the high-energy gamma transitions into two groups. So there can be defined three regions in the gamma energy. The spectra of KX-rays gated by gamma transitions of these three regions are shown in fig.3. The first region consists of usual statistical transitions of $E_\gamma \leq 10$ MeV (see above). The spectrum of KX-rays which were observed in coincidence with gamma transitions of the first region is dominated by KX-rays of compound-like nuclei. There are KX-rays of both target-like and compound-like nuclei in the spectrum of KX-rays gated by gamma transitions of 10 MeV $\leq E_\gamma \leq$ 16 MeV (second region). This fact disagrees with the assumption that the main source of high-energy gamma-rays is the statistical decay of GDR's of the compound nucleus. The KX-rays of compound-like nuclei dominate again in the spectrum of KX-rays gated by gamma transitions of $E_\gamma \geq 16$ MeV (third region). To summarize, the significant increase in the yield of gamma transitions above the exponentially falling tail was observed both in the second and third region of E_γ. The fusion channel dominates in the third region of E_γ, only. The reaction channels which lead to target-like products play an important role in the emission of gamma-rays of the second region.

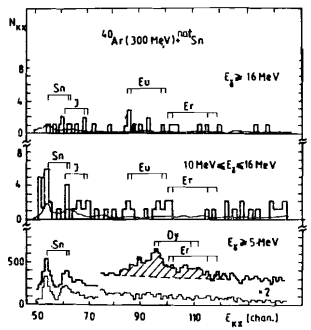

Fig.3. Spectra of KX-rays, which correspond to true coincidence (thick line) and/or to random coincidence (thin line) with different gamma-ranges for the reaction ^{nat}Sn + ^{40}Ar.

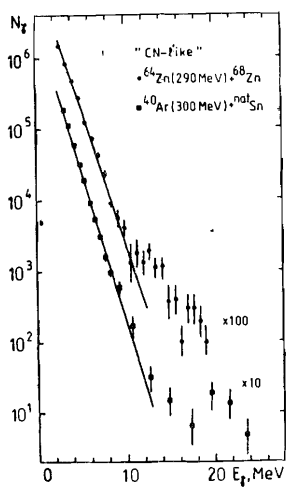

Fig.5. Spectra of gamma-rays registered by the BGO detector in coincidence with KX-rays of compound-like nuclei for the reactions ^{nat}Sn+^{40}Ar (300 MeV) and ^{68}Zn + ^{64}Zn (290 MeV).

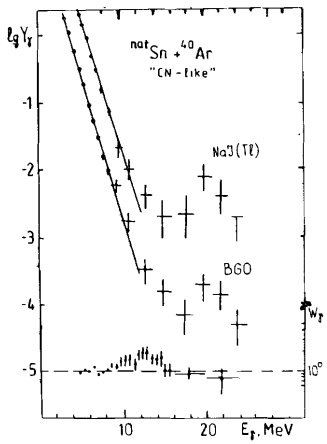

Fig.4. Spectra of gamma-rays registered by the NaI(Tl) detector (top) and BGO detector (middle) in coincidence with KX-rays of compound-like nuclei. The measured ratios of the yields of gamma-rays emitted perpendicularly and along the beam direction W_γ are demonstrated in the bottom part of the figure.

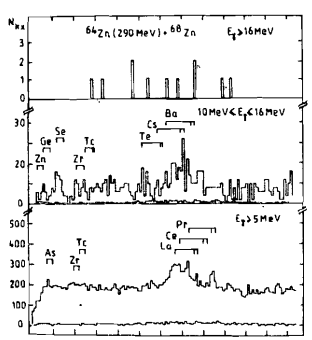

Fig.6. The same as the Fig.3, for the reaction ^{68}Zn + ^{64}Zn.

We have determined the ratio $W_\gamma = Y_\gamma^{90^o}/Y_\gamma^{0^o}$ of the yields of gamma transitions observed at angles of 90° ($Y_\gamma^{90^o}$) and 0° ($Y_\gamma^{0^o}$) to the beam direction and gated by the cascade of soft gamma-rays. The value of W_γ has to depend both on the multipolarity of gamma transitions and on the characteristics of their source. The isotopic emission of gamma-rays of E_γ =(4-8) MeV was observed in the ^{159}Tb + ^{12}C reaction by the authors of paper /11/. Therefore we normalised the observed gamma spectra in the region of E_γ =(4-8) MeV. The resulting values of W_γ are shown as functions of E_γ in fig.4. The value of W_γ is significantly higher than unity in the second region of E_γ. There is no significant deviation of W_γ in the third region of E_γ if one takes experimental errors into accout. These facts indicate again the different character of gamma-ray emission in the second and the third region of E_γ.

It was interesting to compare the gamma spectra measured in both investigated reactions leading to the compound (residual) nuclei Yb and Er. This comparison is shown in fig.5. An increase in the yield of gamma-rays for $E_\gamma \geq$ 10 MeV in going to the reaction ^{68}Zn+^{64}Zn with a ratio $A_1/A_2 \approx 1$ has been observed. This result is in agreement with the conclusions of a previous paper /10/.

The spectra of KX-rays for the reaction ^{68}Zn+^{64}Zn measured in coincidence with the same ranges of E_γ as for the reaction ^{nat}Sn+^{40}Ar are shown in fig.6. For the gamma energy range 10 MeV$\leq E_\gamma \leq$16 MeV as well as for $E_\gamma \geq$ 16 MeV KX-rays are connected with the Z of the residual nucleus close to the Z of the compound nuclei.

Conclusion

Our data show that in the ^{nat}Sn+^{40}Ar reaction, the main part of gamma transitions is connected with deep-inelastic collisions in the range E_γ =(10-16) MeV. This conclusion is in contradiction with the one made in previous papers /5-8/. The yield of gamma-rays connected with the fusion channel is dominant in the gamma energy range E_γ = =(16-22) MeV. The increase of the gamma-ray yield emitted perpendicularly to the beam direction in the range E_γ =(10-16) MeV and the nearly isotopic angular distribution of gamma-rays in the range E_γ =(18-22)MeV has been observed in the ^{nat}Sn+^{40}Ar reaction, too.

We have observed that the centroid of the part of the γ-spectrum exceeding the exponentially falling tail was shifted to smaller values of gamma-energy in the ^{68}Zn+^{64}Zn reaction, where the masses of projectile and target nuclei are almost equal. The yield of this part of gamma-rays increased significantly, as compared to the ^{nat}Sn+^{40}Ar

reaction. Finally, gamma-rays with $E_\gamma \geq 10$ MeV were mainly due to the fusion channel in the $^{68}Zn+^{64}Zn$ reaction.

Out data indicate that the mechanism of emission of high-energy gamma-rays ($E_\gamma \geq 10$ MeV) is probably more complex than it was assumed in previous papers /5-8/. The gamma-ray emission may be due to the transfer of nucleons between the two interacting nuclei (a change in the shape of the dinuclear system).

Although the data have been obtained in experiments with thick targets and the sums of the masses of projectile and target nuclei differ slightly between the two studied reactions, the observed differences in the data can be due to the values of mass-asymmetry in the entrance channel of the studied reactions. It should be noted that the dependence of the yield of high-energy gamma-rays on the projectile energy, and on the mass of the compound nucleus with $A \sim 150$-200 is weak /10/.

We would like to express our sincere thanks to Academicain G.N.Flerov and Prof. Yu.Ts.Oganessian for their interest in this work and for helpful discussions.

REFERENCES

1. Penionzhkevich Yu.E. et al. "Particles and Nuclei", Moscow, Energoatomizdat, v.17, 2, 1986, p.165.
2. Lazzarini A. et al. Phys.Rev.Lett., 53, 1984, p.1045.
3. Arctaedius Th. et al. Phys.Lett., 158B, 1985, p.205.
4. Cabot C. et al. Z.Phys., A322, 1985, p.393.
5. Snover K.A. Jour.Phys., 45, 1985, p.C4-337.
6. Newton J.O. et al. Phys.Rev.Lett., 36, 1981, p.1383.
7. Gaardhoje J.J. et al. Phys.Lett., 139B, 1984, p.273.
8. Haas B. et al. Phys.Lett., 120B, 1983, p.79.
9. Volkov V.V. "Particles and Nuclei", Moscow, Energoatomizdat, v.6, 1975, p.1040.
10. Kamanin V.V. et al. JINR Rapid Communications, 8-85, Dubna, 1985, p.18.
11. Bardgholtz Ch. et al. J.Phys.G: Nucl.Phys., 10, 1984, p.L275.

Received by Publishing Department
on July 9, 1986.

SUBJECT CATEGORIES OF THE JINR PUBLICATIONS

Index	Subject
1.	High energy experimental physics
2.	High energy theoretical physics
3.	Low energy experimental physics
4.	Low energy theoretical physics
5.	Mathematics
6.	Nuclear spectroscopy and radiochemistry
7.	Heavy ion physics
8.	Cryogenics
9.	Accelerators
10.	Automatization of data processing
11.	Computing mathematics and technique
12.	Chemistry
13.	Experimental techniques and methods
14.	Solid state physics. Liquids
15.	Experimental physics of nuclear reactions at low energies
16.	Health physics. Shieldings
17.	Theory of condenced matter
18.	Applied researches
19.	Biophysics

Каманин В.В. и др.

E7-86-457

Сравнение выходов высокоэнергетических гамма-квантов с $E_\gamma \geq 10$ МэВ, измеренных в реакциях $^{\text{ест}}Sn + {}^{40}Ar$ и $^{68}Zn + {}^{64}Zn$

В реакциях $^{\text{ест}}Sn + {}^{40}Ar$ и $^{68}Zn + {}^{64}Zn$ при энергии ионов аргона 300 МэВ и цинка 290 МэВ измерялись спектры КХ-квантов в совпадении с гамма-квантами /$E_\gamma \geq 10$ МэВ/ продуктов реакции. В спектрах КХ-квантов обнаружились две характерные группы. Первая соответствует продуктам испарительного канала реакции и вторая - продуктам, близким по массе к ядру мишени. В обоих реакциях измерялись спектры гамма-квантов в совпадении с КХ-квантами испарительных продуктов. Относительный выход и положение широкого пика, наблюдаемого при энергии $E_\gamma \geq 10$ МэВ сильно отличается для симметричной и асимметричной системы. Было определено отношение между выходами гамма-квантов под углами 0° и 90° в реакции $^{\text{ест}}Sn + {}^{40}Ar$. Найдено, что оно отличается от единицы только в области E_γ = /10-14/ МэВ. Анализ экспериментальных данных показывает, что возможным источником высокоэнергетических гамма-квантов является двойная ядерная система, испускающая их до образования составного ядра.

Работа выполнена в Лаборатории ядерных реакций ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1986

Kamanin V.V. et al.

E7-86-457

Comparison of thr Yields of High-Energy Gamma-Rays with $E_\gamma \geq 10$ MeV Measured in the Reactions $^{\text{nat}}Sn + {}^{40}Ar$ and $^{68}Zn + {}^{64}Zn$

The spectra of KX-rays of reaction products were measured in coincidence with high-energy gamma-rays ($E_\gamma \geq 10$ MeV) in the $^{\text{nat}}Sn + {}^{40}Ar$ (E = 300 MeV) and $^{68}Zn + {}^{64}Zn$ (E = 290 MeV) reactions. Two groups of KX-rays can be clearly identified in the spectra. The first one corresponds to the evaporation residue of the compound nucleus and the second one to the target-like products of the reaction. The spectra of gamma-transitions gated by the KY-rays of the evaporation residues were measured in both reactions. The relative yields and the positions of the broad shoulders observed at $E_\gamma \geq 10$ MeV energy in these spectra differ drastically in the asymmetric and symmetric systems. The ratio between the yields of gamma-rays emitted at 0° and 90° angles to the beam direction was determined in the $^{\text{nat}}Sn + {}^{40}Ar$ reaction. It has been found to be greater than unity only at E_γ = (10-14) MeV. This experimental evidence may indicate the emission of high-energy gamma-rays from the dinuclear system prior to the formation of the compound nucleus.

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1986