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A.N.Andreyev, D.D.Bogdanov, V.I.Chepigin,
V.A.Gorshkov, A.P.Kabachenko, A.N.Kuznetsov,
Sh.Sharo, G.M.Ter-Akopian, A.V.Yeremin

CROSS SECTIONS AND ALPHA DECAY PROPERTIES OF THE Ac, Th AND Pa ISOTOPES PRODUCED IN THE $^{205}Tl + ^{22}Ne$ REACTION

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1. INTRODUCTION

The production and alpha-decay properties of many Ac, Th, and Pa isotopes and their daughter products were investigated at Berkeley in the late 60s and early 70s[1,2,3]. The technique, used in these experiments, allowed one to determine only the relative production rates of these isotopes in fusion reactions as a function of the beam energy. Moreover, the complexity of the alpha spectrum in this energy region made it very difficult to identify some of the alpha-peaks and properly determine the line intensities. As there is a considerable discrepancy between some experimental data and theoretical calculations on absolute reaction cross-sections for these nuclei, there is a need, in our opinion, in systematic absolute cross-section determination for this region of neutron deficient nuclei. An additional reason for the study of these nuclei is the need for more accurate determination of their alpha-decay properties.

2. EXPERIMENTAL

The experiments were performed with a ^{22}Ne beam from the U-400 cyclotron of the Laboratory of Nuclear Reactions, JINR, Dubna, with beam intensities $(2\text{-}4)\times10^{11}$ s^{-1}. The ^{22}Ne ion energies were chosen using aluminium and titanium absorbers to cover the energy interval 90-120 MeV. To separate the evaporation residues, which recoiled from the thin target, from the projectile beam and target like nuclei, the "Vassilissa"[4] electrostatic separator of complete-fusion reaction products was used (Fig.1). The angular acceptance was chosen to be ±3° with respect to the projectile beam axis.

The detector system which was used to register the evaporation residues and their alpha-decay products, consists of two transmission secondary electron detectors and seven surface barrier detectors. The evaporation residues, after passing through the separator, are implanted into the surface barrier detectors where their subsequent alpha-decay may be observed. The use of seven independent registration channels

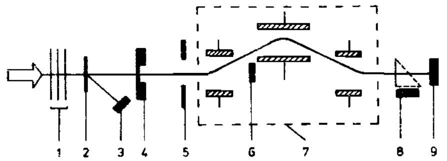

Fig.1. Schematic view of the "Vassilissa facility. 1 - absorbers, 2 - Au scatterer, 3 - detector to determine the energy of the scattered ions, 4 - target, 5 - input diaphragm, 6 - Faraday cup, 7 - separator Vassilissa, 8 - time of flight detectors, 9 - Si(Au) detectors.

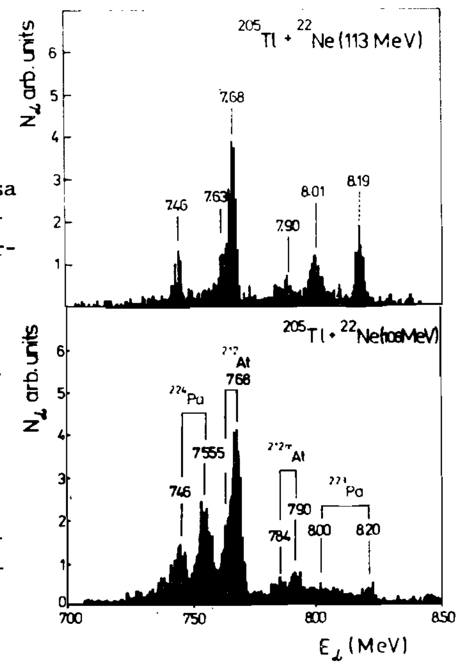

Fig.2. The alpha spectrum from evaporation residues produced in the ^{205}Tl + ^{22}Ne reaction at beam energies of 106 and 113 MeV.

instead of one decreases the probability of accidental coincidences, which is very significant for the correlation analysis.

The electronics, connected to an IBM PC allowed one to register the data from all the detectors in an independent way, giving data to determine the time of flight and energy of the evaporation residues, the time when they impinged upon one of the detectors, the energy and time of their consequent alpha-decays. To register alpha-decays at a time interval < 200 μs the method of alternative ADCs was used. If the first alpha-particle was registered with the first ADC and if, during the dead-time of this ADC, another alpha-particle appeared, then the latter was registered with the second ADC. Moreover, the registration system gives the possibility of recording pile-up pulses, which are occurring when the time interval between two alpha-particles is shorter than the pulse width (~ 5 μs). The system has two built-in clocks, one of them is used to register the time intervals from 5 to 200 μs with an accuracy of 1 μs; the other one, to register the time intervals > 200 μs with an accuracy of 100 μs.

The ^{205}Tl+ ^{22}Ne reaction. For the ^{205}Tl+^{22}Ne nuclear reaction a target of (0.56±0.05) mg/cm^2 thallium was used, consisting of

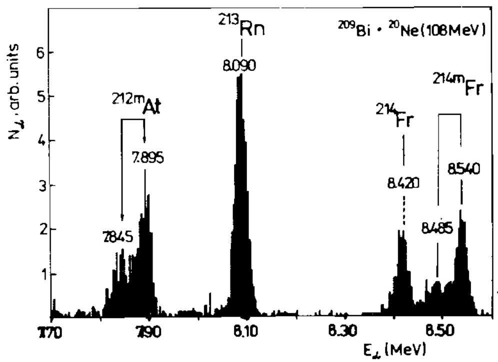

Fig.3. The alpha-spectrum from evaporation residues produced in the ^{209}Bi + ^{20}Ne reaction at a beam energy of 108 MeV.

(99.6 ± 0.1)% ^{205}Tl and 0.4% ^{203}Tl on a 1.57 mg/cm^2 aluminium backing. In fig.2 the alpha-particle spectra of the products of the ^{205}Tl+^{22}Ne reaction for two bombarding energies are shown. The complexity of the spectra does not allow one to make quantitative determination of the particular peaks. For their identification and quantitative determination the method of alpha-mother - alpha-daughter (α_m - α_d) correlation analysis was used.

In the determination of the ^{212m}At alpha-line intensities we observed that, instead of the 65.3%-33.1% ratio/5/ for the 7.837 MeV and 7.897 MeV lines, we have an opposite ratio of ≈33%-66%. For ^{212m}At the same effect was observed in the ^{209}Bi + ^{20}Ne reaction. In the alpha-spectra of this reaction (Fig.3) we observed a large change in the line intensity ratio of ^{214m}Fr, too, where according to ref./3/, the 8.477 MeV and 8.546 MeV lines have an intensity ratio of 50.9%-46%. In both cases the more energetic alpha-peak is more intensive than it should be. Searching for an explanation of this effect, we came to the opinion that we have observed the same effect which was observed in nuclear reactions using the kinematic separator SHIP at Darmstadt/6/. The evaporation residues, impinging upon the surface barrier detectors are penetrating a few μm into their sensitive layer. If an alpha-transition to an excited daughter level takes place, then the following transition to the ground level by internal conversion will produce a conversion electron and Auger electrons. The summation of the ionization caused by these electrons and by the alpha-particle, results in an energy shift. In such a way a certain part of the alpha-transitions to an excited daughter level gives pulses with the same amplitude as belong to a ground-state transition. Because of the lack of sufficient experimental data, we do not intend to give here a quantitative explanation of this effect. For this purpose it is necessary to make a special experiment.

Protactinium 224. In a work of J.B.Borggreen et al./1/ which is a fundamental one for the determination of the alpha-

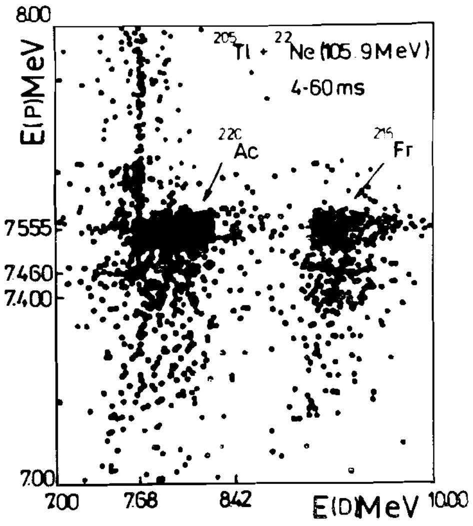

Fig.4. The alpha-alpha-correlation plot for the ^{205}Tl + ^{22}Ne reaction at a beam energy of 106 MeV and a time window of 4-60 ms. E(P) - the energy of the parent nuclei; E(D) - the energy of the daughter nuclei.

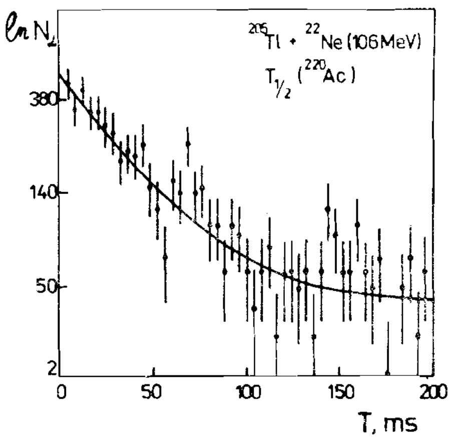

Fig.5. The decay-curve of the alpha-alpha correlation group at an energy of 7.45 MeV of the mother nuclei and of 106 MeV of the ^{22}Ne beam.

decay properties of Protactinium isotopes with masses 222 to 225, the data given for ^{224}Pa, were obtained from the ^{205}Tl(^{22}Ne,3n)^{224}Pa and ^{208}Pb(^{19}F,3n)^{224}Pa nuclear reactions. The authors remark that it was very difficult to determine the intensity of the particular alpha-peaks in the complex alpha-spectra of ^{224}Pa and ^{220}Ac, because of the coincidence and summing-up of the pulses from other alpha-active nuclei. The data for ^{224}Pa from ref./1/ are given in Table 1.

The use of the kinematic separator "Vassilissa" and the method of alpha-alpha correlation analysis allowed us, in the investigation of the ^{205}Tl + ^{22}Ne reaction, to separate the alpha-decay products of ^{224}Pa in a cleaner form than it was possible in the previous experiment/1/. In fig.4 the α_m - α_d correlation plot for the alpha-mother energy E(M) = 7.00 - 8.00 MeV and alpha-daughter energy E(D) = 7.00 - 10.00 MeV for the time window of 4 - 60 ms is shown. At beam energies of 100, 106 and 109 MeV the correlation groups at the alpha-mother energies E_{m1} = 7460 keV and E_{m2} = 7555 keV have the same half-life, $T_{1/2}$ = (26.4 ± 2) ms (Fig.5), which is in good agreement with the half-life of ^{220}Ac/1/. The half-life of the right and the left part of the given correlation groups is

Table 1

The alpha-decay characteristics of some nuclei produced in the ^{205}Tl + ^{22}Ne reaction

Nucl.	This work			Other works		
	E keV	Int. %	$T_{1/2}$ ms	E keV	Int. %	$T_{1/2}$ ms
^{214}Fr	8350 ±10 8423 ±10	6 ±3 94 ±4		\9\ 8358 ±5 8426 ±5	4.7±0.3 93 ±1	5
^{217}Fr	*1	100	16 ± 2 μs	\1\ 8315 ± 8 8315 ± 8	100	22 ±5 μs
^{221}Ac	7160 ±15 7375 ±10 7435 ±10 7650 ±10	2.7 ±0.6 9.2 ±1 21 ±1 66.2 ±3		\1\ 7170 ±10 7375 ±10 7440 ±15 7645 ±10	2 10 ±5 20 ±5 70 ±10	52 ±2
^{223}Th	7290 ±10 7320 ±10 7350 ±15 7390 ±15	41 ±5 29 ±5 20 ±5 10 ±4		\2\ 7285 ±10 7315 ±10 \7\ 7320 ±20 7410 20	60 ±10 40 ±10 81 ± 8 19 6	660 ±10
^{223}Pa	8000 ±10 8190 ±10	55 ±4 45 ±4	7.5±1.5	\8\ 8006 ±10 8196 ±10	55 ±5 45 ±5	6.5
^{224}Pa	7460 ±10 7555 ±10	25 ±3 75 ±3		\1\ 7490 ±10	100	950±150

*1 Not determined bacause of the partial pile-up of the pulses.

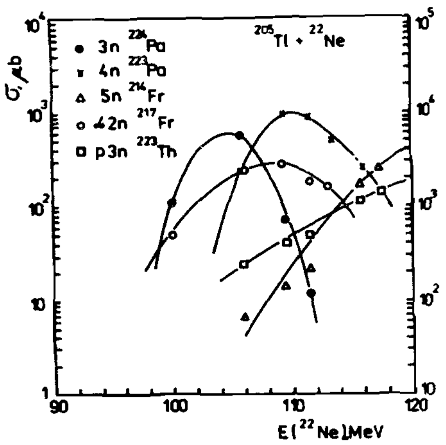

Fig.6. The differential cross-section of the ^{205}Tl + ^{22}Ne reaction products. The left scale stands for α 2n, the right scale is for the xn and pxn evaporation channels.

the same. This is caused by the fact, that ^{216}Fr, the daughter of ^{220}Ac, has a very short half-life - 0.7 μs, and the detector is registering the alpha-particles of ^{216}Fr with the half-life of ^{220}Ac. The large dispersion in energy of the daughter nuclei - ^{220}Ac and ^{216}Fr - in the correlation plot is caused by the partial summing-up of the pulses of two alpha-particles occurring in a time interval shorter than a few μs. The correlation group at E_m = 7.39 - 7.40 MeV has a half-life of (10 ± ± 3) ms and consequently does not belong to ^{224}Pa. The data for ^{224}Pa obtained from the correlation analysis are given in Tab.1. In connection with the observed shift in the energy spectrum, as a result of internal conversion, there is a possibility that the given line intensities of ^{224}Pa are deformed, too. The excitation function of ^{224}Pa (Fig.6) plotted on the basis of the α_m - α_d correlation data, is in good agreement with that given in ref./1/.

Actinium 221 - Francium 217. In the α2n reaction channel leading to the alpha-decay chain ^{221}Ac - ^{217}Fr - ^{213}At the half-life of ^{217}Fr was determined to be (16 ± 2) μs and more accurate line intensities for the ^{221}Ac alpha groups were determined (Tab.1).

Thorium 223. The alpha-decay characteristics of ^{223}Th were investigated at Berkeley/2/ and at Dubna/7/ using the same source, the ^{208}Pb + ^{22}Ne reaction. At Berkeley two alpha-peaks of ^{223}Th were identified (7.28 and 7.32 MeV) having a half-life of 0.66 s.At Dubna, by using alpha-alpha correlation analysis, another peak was identified at 7.41 MeV. Because of the insufficient energy resolution of the detector, it was impossible to determine the ^{223}Th alpha line structure more accurately.In the present work the detecting system allowed us to determine the ^{223}Th alpha-line structure in more detail. In the α_m - α_d correlation plot of the ^{205}Tl + ^{22}Ne reaction products there were identified four correlation groups (Tab.1) belonging to ^{223}Th.

Table 2

The cross section of the production of nuclei in the ^{205}Tl ± ^{22}Ne reaction as a function of the beam energy. The data are given in μbarns. The given accuracy is only the statistical one, the uncertainty due to the target and to the separator is ± 40%.

E(^{22}Ne)	Reaction channel - Nucleus				
MeV	3n ^{224}Pa	4n ^{223}Pa	5n ^{222}Pa	α,2n ^{221}Ac	p3n ^{223}Th
100.1	110 ± 9%			400 ±7%	
105.9	580 ± 5%	240 ±5%	8 ±30%	1920 ±3%	25 ±10%
109.3	70 ± 8%	960 ±2%	15 ±30%	2320 ±4%	40 ±12%
111.5	12 ±17%	905 ±2%	20 ±30%	1480 ±3%	40 ±10%
113		490 ±3%		1360 ±5%	
115.8		265 +3%	175 ± 8%		110 ±6%
117.1			265 ± 7%		140 ±7%

Two correlation groups, at E_{m1} = 7.29 MeV and E_{m2} = 7.31 MeV, have the same relative line intensity, as it was determined at Berkeley/2/, the third one at E_{m3} = 7.35 MeV is identified for the first time and the fourth one at E_{m4} = 7.39 MeV is visible in the alpha spectrum measured at Berkeley, but not identified. The complex character of the ^{223}Th alpha-spectrum does not exclude the existence of other, weaker alpha lines in the given energy region.

The cross section of the 3n, 4n, 5n, p,3n and α2n evaporation channel of the ^{205}Tl + ^{22}Ne reaction at different beam energies are given in Table 2 and plotted in Fig.6.

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Андреев А.Н. и др. E15-89-683

Сечения образования нуклидов Pa, Th и Ac в реакции ^{205}Tl+^{22}Ne и уточнение характеристик их α-распада

Эксперименты выполнялись с использованием кинематического сепаратора ядер отдачи Василиса. В реакции полного слияния ^{22}Ne+^{205}Tl изучены поперечные сечения образования изотопов $^{222-224}$Pa, ^{223}Th и ^{221}Ac. С помощью метода α-α корреляционного анализа уточнены характеристики α-распада изотопов ^{223}Th, ^{224}Pa, ^{217}Fr. Обнаружен эффект искажения относительных интенсивностей α-линий для некоторых нуклидов, обусловленный, по видимому, аппаратурным эффектом.

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Cross Sections and Alpha Decay Properties of the Ac, Th and Pa Isotopes Produced in the ^{205}Tl+^{22}Ne Reaction

In the fusion reaction of ^{22}Ne with ^{205}Tl the cross sections for producing the $^{222-224}$Pa, ^{223}Th, and ^{221}Ac isotopes were measured. The experiments were carried out using the "Vassilissa" kinematic separator. Two alpha lines of ^{224}Pa were found with energies of 7460±10 keV (25±3%) and 7555±10 keV (75±3%); four alpha lines of ^{223}Th were found with energies of 7290±10 keV (41±5%), 7320±10 keV (29±5%), 7350±15 keV (20±5%), and 7390±15 keV (10±4%). The half-life of ^{217}Fr was measured to be 16±2 μs. For some isotopes considerable changes in the relative intensities of alpha lines were observed, due to the effect, associated with the method of detection.

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

Communication of the Joint Institute for Nuclear Research. Dubna 1989