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LOW TEMPERATURE NUCLEAR ORIENTATION OF ^{238}NpGd

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1. INTRODUCTION

The region of heavy actinide nuclei with mass number in the range $228 \le A \le 254$ has been known for a long time to display large equilibrium deformations. Most of the even-even nuclei of this group can be well described in terms of the collective models of the nucleus. The results of theoretical calculations of energies of some collective non-rotational excited states and those of two-quasi-particle neutron and proton states up to 2 MeV for strongly deformed even-even nuclei including the nucleus ^{238}Pu are tabulated in work of Soloviev et al./1/.

The nuclear structure of the ^{238}Pu nucleus was investigated by a variety of experimental methods including nuclear reactions and measurements of the alpha-decay of ^{242}Cm, EC decay of ^{238}Am and beta-decay of ^{238}Np. The results of these experiments were recently summarized and published in a volume of Nuclear Data Sheets /2/.

The measurement of the energies and intensities of gamma-rays following the beta-decay of ^{238}Np, their placement in a level scheme and analysis of gamma-ray branching ratios in ^{238}Pu was carried out by Palms et al./3/ and by Winter et al./4/. The long living level at 1082.6 keV was established and its lifetime was determined by Bengtson et al. /5/. The study of conversion electrons and the assignment of multipolarities was performed by Lederer /6/ in his investigation of the beta-decay of ^{238}Np and alpha-decay of ^{242}Cm and by Ahmad et al. /7/ in a study of the EC decay of ^{238}Am.

All these investigations yielded a quite complex information about the level scheme of ^{238}Pu nucleus. Nevertheless until now nothing was known about the multipole mixing ratios of gamma-transitions between individual levels of ^{238}Pu.

The aim of the present work was to measure some of the unknown mixing ratios of transitions between low-lying levels in ^{238}Pu excited in the beta-decay of ^{238}Np. In a previous study of nuclei of this region we have found that the orientation parameter of ^{239}Np in a gadolinium host at low temperatures is rather high /8/. This was the reason for applying the method of low-temperature nuclear orientation also for the study of the decay of ^{238}Np in gadolinium.

2. EXPERIMENTAL

The ^{238}Np radionuclide was produced by irradiation of 14 μg of ^{237}Np in IBR-2 experimental nuclear reactor in JINR Dubna in a thermal neutron flux of 1.10^{12} $sec^{-1}.cm^{-2}$ for 8 hours, and measured after 24 hours of cooling. The ^{238}NpGd sample was prepared by melting the radionuclide with gadolinium metal in a vacuum furnace and cooled down to T≃15 mK in ^{3}He-^{4}He dilution refrigerator of the JINR nuclear orientation facility SPIN /9/. An external magnetic field of 1.3 T was applied to the sample to polarize the magnetic domains of the host.

The gamma-ray spectra were measured using two coaxial Ge(Li) detectors having the active volume of 32 cm^{2} and the resolution of about 2.3 keV FWHM at 1.3 MeV gamma-ray energy. The spectra were taken simultaneously at emission angles $\vartheta=0°$ and $\vartheta=90°$ relative to the external magnetic field direction. Typical spectra obtained are shown in Fig. 1. The intensities of the gamma-rays observed were determined using the peak fitting routine KATOK /10/ adapted for the use on an IBM PC compatible mini-computer Pravetz 16 /11/.

The intensities found were normalized to a set of measurements carried out at 800 mK when the source ensemble was considered to be fully random ("warm" experiment). The gamma-ray anisotropies were calculated after correcting all the measurements for the decay of the source.

3. RESULTS AND DISCUSSION

The averaged intensities of dominant gamma-rays measured in four independent "cold" runs were normalized to the values found in "warm" experiments. An attempt was made to make an estimate of normalized intensities of some weak transitions in ^{238}Pu from the spectra obtained

Table 1
Normalized intensities of gamma rays observed in the decay of oriented ^{238}Np

E_γ[keV]	W(0)-1	1-W(90)	E_γ[keV]	W(0)-1	1-W(90)
1028.5	-0.20(2)	-0.17(2)	918.6	0.04(3)	0.04(2)
1025.8	-0.08(4)	-0.08(4)	882.6	-0.07(2)	-0.01(2)
984.4	0.07(2)	0.01(1)	617.3	0.3(2)	0.3(1)
962.8	0.40(2)	0.18(2)	605.1	0.5(2)	
941.3	-0.16(2)	-0.11(2)	561.1	0.2(1)	-0.01(9)
936.6	-0.16(3)	-0.09(3)	515.5	-0.1(2)	0.2(3)
923.9	0.26(1)	0.116(8)	421.1	0.5(7)	-0.02(38)

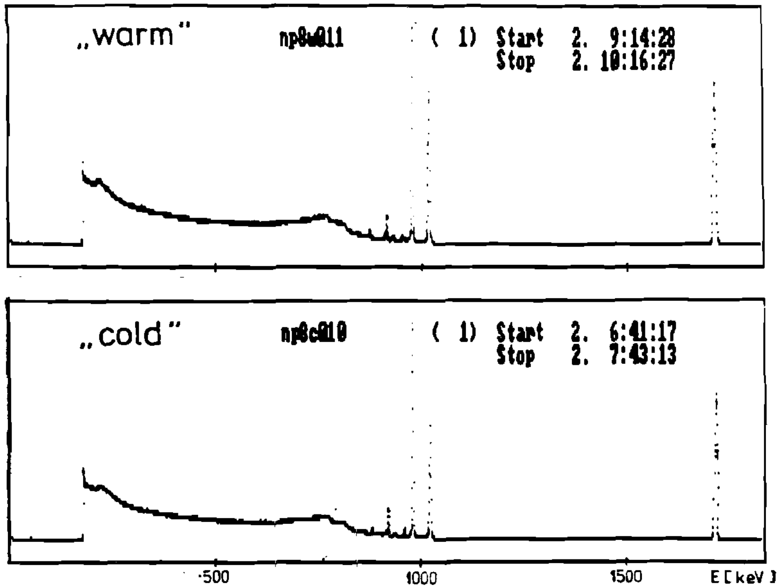

Fig. 1 The gamma-ray spectra of ^{238}Np measured at ≃ 800 mK and at 15 mK

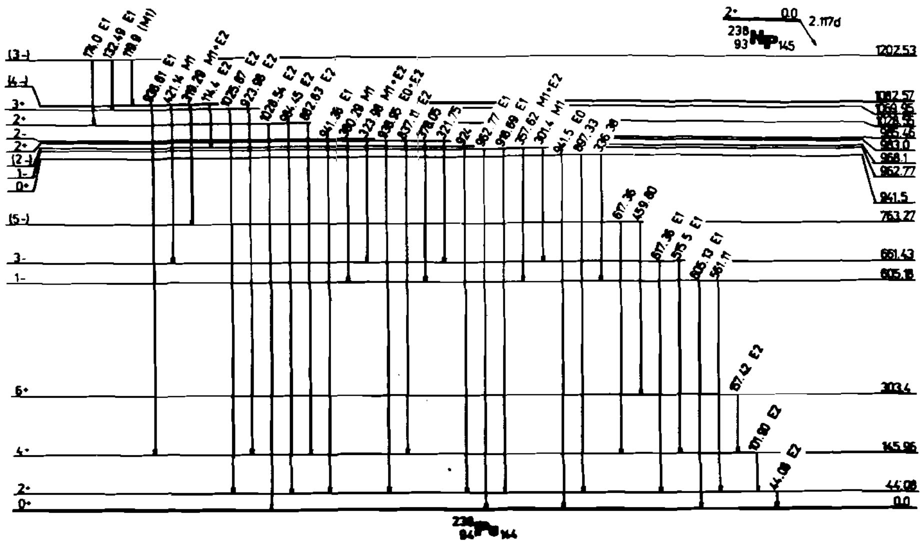

Fig. 2 The decay sheme of ^{238}Np /2/

by summation of the experimental spectra. The results of these calculations are given in Table 1.

In the analysis of our experimental data the decay scheme of ^{238}Np (I^{π}= 2^{+}, $T_{1/2}$= 2.117 d) published in Nuclear Data Sheets /2/ (see Fig. 2) was used. The data measured were treated by a system of fitting programs /11/ installed on an IBM PC compatible mini-computer. This system enabled simultaneous fitting of orientation parameters Bk, multipole mixing ratios δ and attenuation parameters G_k.

The values of orientation parameters obtained are

B_2= 0.92(2) and B_4= 0.12(3).

Deorientation parameters U_2 and U_4 for individual levels in ^{238}Pu were calculated. No attenuation was observed for the isomeric state at the level 1082.57 keV having half-life $T_{1/2}$= 8.5 ns. The experimental value of the attenuation factor for this level was G_2= 0.98(14). From this result it follows that the deorientation of this long-living level does not influence the deorientation coefficients U_k. This is consistent even with the estimate of the attenuation factor G_4 ($G_4 \simeq$ 1).

Multipole mixing ratio for beta-transition to the level 1028.6 keV obtained by a system of fitting programs /11/ from our experimental data is shown in Table 2.

Table 2
Multipole mixing ratios for beta-decay of ^{238}Np

E_f[keV]	$I_i^{\pi} \rightarrow I_f^{\pi}$	$\delta \left(\frac{\Delta L=1}{\Delta L=0}\right)$	$Q \left(\frac{\delta^2}{1+\delta^2}\right)$
1028.55	$2^{+} \rightarrow 2^{+}$	10(,-3)	0.99(1,-2)

From these values it follows that this transition is predominantly Gamow-Teller transition. This result is in agreement with the isospin selection rules which tend to inhibit the Fermi component /12/.

The results of calculations of multipole mixing ratios E2/M1 or M2/E1 for nine gamma-transitions measured are demonstrated in Table 3. The anisotropies measured for transitions 1028.5 keV ($2^{+} \rightarrow 0^{+}$), 882.6 keV ($2^{+} \rightarrow 4^{+}$), 962.8 keV ($1^{-} \rightarrow 0^{+}$) and 605.1 keV ($1^{-} \rightarrow 0^{+}$) which have pure multipolarity are not included in the table. Their angular distribution coefficients agree well with their location in the decay scheme.

Table 3
Multipole mixing ratios for gamma-transitions in ^{238}Pu

E_i[keV]	E_{γ}[keV]	I_i^{π}	I_f^{π}	M	A_2	A_4	δ
1082.5	936.6	4^-	4^+	M2/E1	-0.25(4,-3)	-0.03(1,-1)	-0.24(4,-4)
1069.9	1025.9	3^+	2^+	E2/M1	-0.16(3,-3)	0.67(1,-1)	56.(,-25)
	924.0	3^+	4^+	E2/M1	0.34(1,-2)	0.15(1,-1)	44.(72,-8)
1028.5	984.4	2^+	2^+	E2/M1	0.10(3,-2)	-0.31(1,-1)	37.(,-14)
985.4	941.4	2^-	2^+	M2/E1	-0.20(2,-2)	-0.01(2,-2)	-0.17(1,-2)
962.7	918.7	1^-	2^+	M2/E1	0.05(9,-2)	0.000	-0.02(11,-3)
661.4	617.4	3^-	2^+	M2/E1	0.7(2,-3)	0.02(5,-2)	-0.2(1,-2)
	515.5	3^-	4^+	M2/E1	-0.1(3,-4)	0.01(5,-1)	-0.2(2,-5)
605.1	561.1	1^-	2^+	M2/E1	0.4(3,-4)	0.000	0.3(,-4)

From the data shown in Table 3 it can be seen that the hindered E1 936.6 keV transition depopulating the long-living level at 1082.5 keV has a rather high M2 admixture (about 5%). The precision of the δ values of the other E1 transitions is rather pure due to their small intensities. For M1+E2 transitions the higher values of the two possible roots of the quadratic equation for δ were chosen in agreement with the results of ICC measurements /2/.

4. CONCLUSIONS

In agreement with the previous results /8/ the orientation of neptunium in gadolinium host is relatively high even when compared to that found by Krane for the intermetallic compound $(U_xZr_{1-x})Fe_2$ /13/. The magnetic moment of the ground state of ^{238}Np is not known and it could not be determined in our experiment due to the lack of information on the hyperfine field acting on Np in the gadolinium matrix.

The experimental data were analysed using the values of spins and parities as given in the level scheme of ^{238}Pu /2/. The results obtained confirm the spin/parity assignements of single levels in the decay scheme and the multipolarities of transitions. This fact is also in agreement with theoretical predictions of collective models /1/.

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