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A STUDY OF LEVELS IN ^{92}Mo AND ^{94}Ru BY IN-BEAM GAMMA-RAY SPECTROSCOPY†

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Information is presented on the level energies, spins, parities, and lifetimes of excited states of the 50-neutron nuclei ^{92}Mo and ^{94}Ru, as observed "in-beam" following (α,2n) reactions in the 88-inch cyclotron. The existence of a four-proton excited configuration, $(p_{1/2})(g_{9/2})^3$, is deduced from the data.

†Work performed under the auspices of the U. S. Atomic Energy Commission.

We report here the results of a study of the excited states of the 50-neutron nuclei ^{92}Mo and ^{94}Ru populated by (α,2n) reactions at the Berkeley 88-inch cyclotron. In the experiments, Ge(Li) detectors were used "in-beam" to observe the γ rays emitted from isotopically enriched targets ^{90}Zr and ^{92}Mo irradiated with 30-MeV α particles. The γ-ray spectra were recorded in the time intervals between beam pulses in the cyclotron. These pulses, which are produced by the natural bunching of the beam, have a width of about 4 nsec and a spacing of 163 nsec for 30-MeV α particles. Thus, half-lives of isomeric states within the approximate limits 2 to 500 nsec can be determined by measuring the time distributions of γ rays relative to the preceding beam pulse[1]. A more complete description of the experimental procedures used in this investigation will be given in a forthcoming paper[2].

Following preliminary experiments that included both singles γ-ray spectroscopy and some 2-dimensional measurements (γ-ray energy vs time), a more detailed study of individual isomers was carried out. Figure 1 shows the time distributions of the γ rays observed in the ^{90}Zr(α,2n)^{92}Mo reaction. Two distinct half-lives are evident, 8.8±0.5 nsec and 220±30 nsec, as derived from least squares fitting of the data. The decay curves of the 244-, 773-, and 1511-keV transitions represent sums of two exponentials with the above half-lives.

The time distribution measurements allow one to distinguish between isomeric transitions and subsequent cascade transitions, since the latter show a prompt component due to direct population. Thus, the 235- and 147-keV transitions in ^{92}Mo are identified as isomers. It is also possible to deduce unambiguously the order of γ rays in a cascade following an isomeric transition by the relative intensities of their prompt components, which increase monotonically down the chain.

In the case of the 147-keV isomeric transition, it is difficult to ascertain the absence of a prompt component, because of the presence of another prompt γ ray of nearly the same energy. However, its assignment as an isomer was supported by the observation of an isotropic angular distribution in contrast to the large anisotropies observed for the prompt cascade transitions. This attenuation of angular anisotropy occurred because the relaxation time in our targets was much shorter than the lifetime of the isomeric transition. The angular anisotropies of delayed γ rays were found to be almost totally attenuated in 30 nsec. The 235-keV isomeric transition showed an attenuated distribution for the same reason.

Figure 2 shows the level schemes of ^{92}Mo and ^{94}Ru that were deduced from this work. The cascade relationships were confirmed by coincidence measurements made with two Ge(Li) detectors, and the ordering of the transitions was inferred from the intensity considerations discussed above. The spin assignments are based on observed angular distributions of the γ rays relative to the beam direction, plus additional information concerning the presence of absence of cross-over transitions. Newton et al.[3)] and Yamazaki[4)] have discussed the interpretation of angular distribution measurements in "in-beam" γ-ray spectroscopy.

In ^{92}Mo, the energies of the levels up to the 8+, and the half-life of the 8+ ——> 6+ transition, are in agreement with previous results[5)]. The 2528-keV level is probably the 5- state which has been well characterized in ^{90}Zr. The 244-keV transition from this state to the 4+ state has an angular distribution characteristic of stretched dipole transitions, in contrast to the quadrupole distributions of most of the ^{92}Mo γ rays.

The even-parity levels in ^{92}Mo and ^{94}Ru can be described as predominantly $(g_{9/2})^2_\pi$ excitations. The odd-parity levels found in ^{92}Mo appear to constitute a "band" of related excitations based on the 5- state. The probable configuration of this state, $(p_{1/2})_\pi$ $(g_{9/2})_\pi$, and the spin of the highest observed member of the band, 11, suggest a description of this band in terms of the four-proton configuration $(p_{1/2})$ $(g_{9/2})^3$. The large observed transition probability of the 11- ⟶ 9- electric quadrupole transition, 3.6 single particle units[6], also lends support to the hypothesis that these levels arise from the same configuration.

Ball et al. have recently performed calculations of the even- and odd-parity levels of ^{92}Mo and ^{94}Ru. These calculations, and a comparison between theory and experiment, are the subjects of the following letter[7]. We note here with regard to ^{92}Mo only that we have observed all the states that would be expected to appear on the basis of the theoretical level ordering and the fact that the reaction mechanism favors initial production of high angular momentum states[8].

In ^{94}Ru we fail to find an isomer analogous to the 4487-keV state of ^{92}Mo. If the half-life of such an isomer were greater than ≈2 nsec, it would be detected both by observation of the isomeric transition itself and from delayed components in the decay curves of the following cascade transitions. Even if the half-life of the isomeric transition were shorter than 2 nsec, it would appear in the spectrum coincident with following transitions (439-, 691-, and 1033-keV) if it were of sufficient intensity. From our negative results, we can set an upper limit on the population of the 11- isomer state in ^{94}Ru as about one-third the intensity of the 691-keV transition. This situation contrasts with that of ^{92}Mo, where almost all the population of the odd-parity band feeds through the 11- state.

It had been noted in the cyclotron experiments that the half-life of the 8+ state in ^{94}Ru was outside our measurable range, therefore a measurement of the decay of the 145- and 311-keV transitions was made in the pulsed 28-MeV α-particle beam of the Heavy Ion Linear Accelerator. In this measurement both transitions were found to have the same half-life, 71±5 μsec. In the shorter time interval between pulses at the cyclotron, the 311-keV γ ray appeared also to have a short-lived component, whose presence was verified by a coincidence measurement of the delay between the 147-keV and 311-keV γ rays. This short component, $t_{1/2}$ = 74±7 nsec, is therefore assigned to the 6+ level of ^{94}Ru. The 71-μsec half-life is assigned to the 8+ level, but only tentatively for the reasons noted below.

Transitions in the even-parity band of ^{94}Ru are highly retarded relative to the corresponding transitions in ^{92}Mo. This effect, the result of adding more particles to the $g_{9/2}$ orbital, is in reasonable quantitative agreement with the calculations of Ball et al.[7)] for the half-lives of the 6+ ⟶ 4+ transitions. However, the half-life of the 8+ level of ^{94}Ru relative to that of the 6+ level disagrees with the calculated ratio by a factor of 13. This is especially surprising in view of the fact, mentioned by Ball et al., that the 8+ and 6+ level lifetimes should be simply related by a common effective quadrupole moment for the $g_{9/2}$ proton. We have considered the possibility that the 71-μsec half-life is actually that of a transition preceding the 8+ ——> 6+ transition, but there is no other evidence for such a transition, and also the calculations of Ball et al. do not predict another isomeric state for ^{94}Ru in this energy region.

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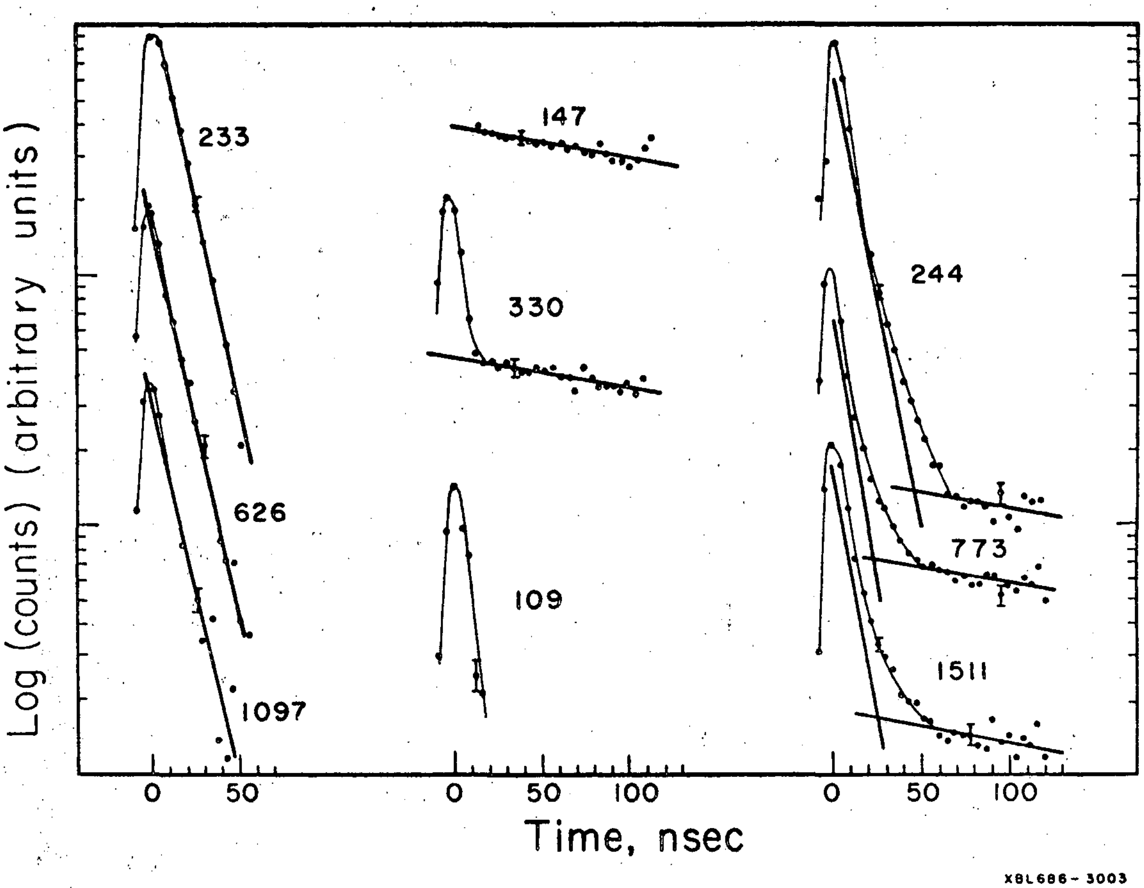
Figure Captions

Fig. 1. Decay curves for the transitions observed in $^{90}Zr(\alpha,2n)^{92}Mo$ reaction.

Fig. 2. Level schemes of ^{92}Mo and ^{94}Ru.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0
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Time, nsec
XBL686-3003

Fig. 1

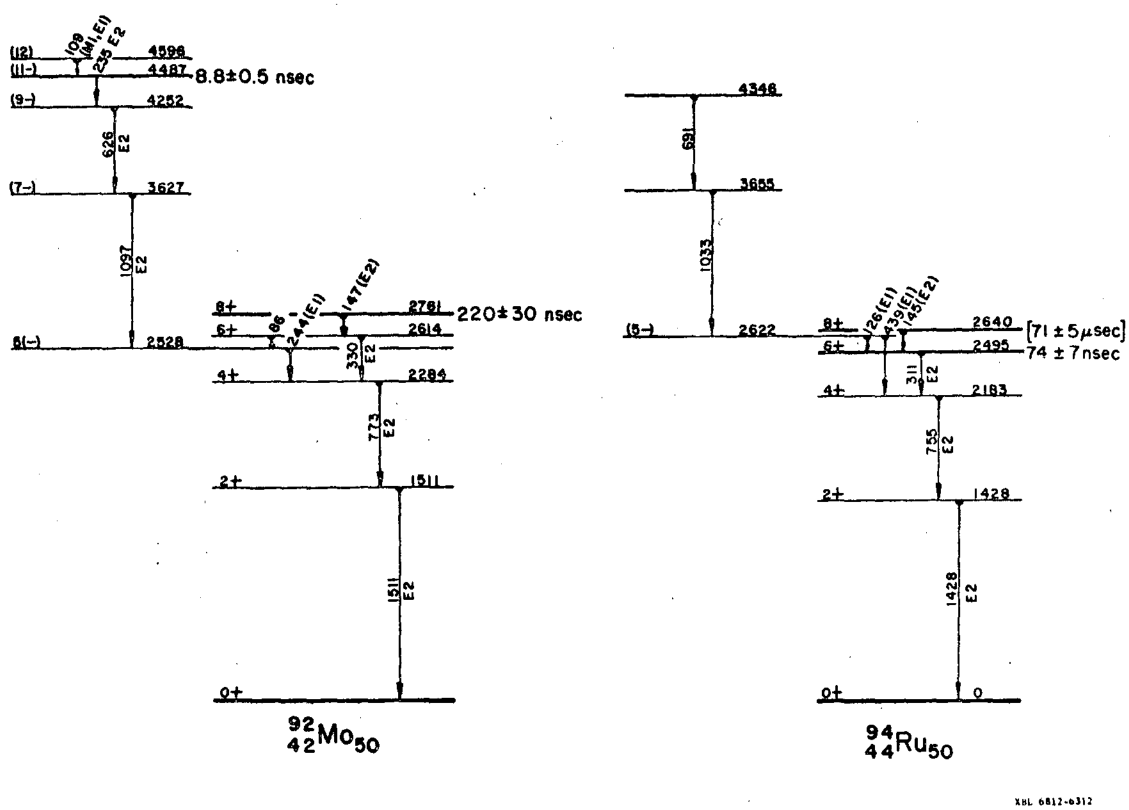

Fig. 2

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