Nuclear Energy Levels Excited by Fast Neutrons*

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Fast-neutron inelastic scattering has been studied in a number of elements by observation of the de-excitation gamma rays with a single-crystal NaI(Tl) spectrometer. Neutrons of energy 4.4±0.1 Mev were used to bombard isotopically enriched scatterers of Ti, Cr, Ni, Zn, Ge, and W, and normal scatterers of Cl, Sr, Nb, Nd, Sm, and Gd. The low-lying levels in Ti^{47}, I, and W are studied using neutron energies between 0.50 Mev and 1.45 Mev. Energies and relative yields of the gamma rays are given, and their assignment to various excited states is discussed. Previously unknown states were found in Ti^{48}, Cr^{50}, Zn^{64}, Zn^{66}, and Ge^{74}.

INTRODUCTION

THE work described herein is a study of the de-excitation gamma rays following fast-neutron scattering. The use of enriched isotopes of some of the elements investigated has made possible positive isotopic assignments of the observed gamma rays, and the detection of radiation from the less abundant isotopes. The gamma rays have been assigned to various excited states of the nuclei by arguments based on their energies and yields, as well as by comparison with the results of other experiments.

EXPERIMENTAL

All of the gamma rays, except those from the tungsten isotopes and the low-energy radiation from Ti^{47}, were studied by a method described previously.[1,2] Neutrons of energy 4.4±0.1 Mev were produced by the bombardment of a deuterium-gas target with deuterons from the Westinghouse electrostatic generator. A $1\frac{1}{2}$-in.×$1\frac{1}{2}$-in. cylindrical NaI(Tl) crystal, shielded from the neutron source by a 10-inch tungsten wedge, was used to detect gamma rays from various scatterers exposed to the neutrons. The calibration of this spectrometer was effected by interleaving pulse-height spectra from radioisotopes between those obtained with a scattering sample.[2] The stability of the electronics has been improved since the previously reported work, and the measurements of the energy of a given gamma ray were often reproducible to within several kev. The probable errors given here, however, are twice those calculated from the spread of the data or 10 kev, whichever is the greater. This is done to allow for systematic errors, mainly associated with locating the position of the total absorption peaks, and because of the belief that ±10 kev represents the best accuracy now obtainable with this spectrometer for gamma rays of this energy range (0.5 Mev to 1.5 Mev). Relative yields were obtained as described previously.

Isotopically enriched samples of titanium, chromium, nickel, zinc, germanium, and tungsten were obtained on loan from the Stable Isotopes Research and Development Division, Oak Ridge National Laboratory. Each sample was in the elemental form as a 1-in.×1-in. block, and thickness given by the quantity of material available. Table I gives the weights and enrichments of these samples. In addition, niobium, which is monoisotopic[3] was investigated, using a larger metal plate ($3\frac{1}{8}$ in.×$3\frac{1}{2}$ in.×$\frac{3}{16}$ in., 292 grams) placed at 45° to both the incident neutrons and the axis of the crystal.

Chlorine, strontium, neodymium, samarium, and gadolinium were studied using naturally polyisotopic scatterers. Only the energies of the gamma rays were measured for these elements, and yield data were not obtained. Each scatterer was in the elemental form except that for chlorine, which was hexachloroethane. These scatterers were also 1-in.×1-in. blocks and weighed ~50 grams.

The low-energy (~100 kev) gamma rays from Ti^{47} and the tungsten isotopes were studied by a method

TABLE I. Isotopic composition and weight of the enriched scatterers as reported by the Oak Ridge National Laboratory.

Isotope	Enrichment (%)	Other isotopes present[a] (>5%)	Weight (grams)	ORNL lot number
Ti^{46}	84.4	Ti^{48} (11.8%)	3.638	GA752(a)
Ti^{47}	70.0	Ti^{46} (12.9%), Ti^{48} (15.1%)	2.570	GA753(b)
Ti^{47}	82.7	Ti^{48} (14.0%)	2.906	GA753(a)
Ti^{48}	97.6	None	37.480	GA754(a)
Ti^{49}	27.5	Ti^{48} (69.6%)	4.128	GA755(b)
Ti^{50}	80.3	Ti^{48} (12.2%)	1.402	GA756(a)
Ti^{50}	71.4	Ti^{48} (14.3%), Ti^{49} (11.5%)	1.578	GA756(b)
Cr^{50}	75.2	Cr^{52} (22.7%)	3.878	GS840(a)
Cr^{52}	99.7	None	27.012	GZ869(a)
Cr^{54}	79.6	Cr^{52} (13.6%), Cr^{53} (6.1%)	2.882	GR839(c)
Ni^{60}	98.5	None	5.417	FJ670(a)
Zn^{66}	93.8	None	4.843	EK557(a)
Zn^{68}	95.5	None	2.783	EK559(a)
Ge^{70}	91.4	None	9.875	FZ747(a)
Ge^{72}	94.9	None	15.300	FZ748(a)
Ge^{73}	78.0	Ge^{74} (11.1%), Ge^{72} (7.7%)	3.036	FZ749(a)
Ge^{74}	95.8	None	17.284	FZ750(a)
Ge^{76}	81.0	Ge^{74} (9.5%)	5.144	FZ751(a)
W^{182}	92.3	None	7.875	EL562(a)
W^{183}	82.6	W^{184} (10.6%)	3.043	EL563(a)
W^{184}	95.1	None	8.379	EL564(a)
W^{186}	97.5	None	6.425	EL565(a)

[a] Other elements present in negligible amounts.

* Assisted by the Office of Naval Research, the U. S. Atomic Energy Commission, and the Wright Air Development Center.

[1] R. M. Sinclair, Phys. Rev. **99**, 1351 (1955).

[2] R. M. Sinclair, Phys. Rev. **102**, 461 (1956).

[3] White, Collins, and Rourke, Phys. Rev. **98**, 1174(A) (1955).

described by Guernsey and Wattenberg.[4] A 1-mm thick by 1-in. diameter NaI(Tl) crystal was mounted with a 0.001-in. aluminum reflector on a 6291 photomultiplier. Neutrons were produced by the proton bombardment of a 100-kev thick zirconium-tritium target. The crystal was placed 3 inches from the target at 0° to the incident charged-particle beam, and the entire target-crystal-phototube system was surrounded by a 5-in. diameter, $\frac{1}{4}$-in. thick lead shield. No shielding was placed between the neutron source and the crystal.

Each scatterer was taped to a 1-in.×1-in.×$\frac{1}{8}$-in. lead block. With the scatterer placed against the crystal, the pulse-height spectrum of the gamma rays from neutron scattering in the sample was superimposed on that due to the interaction of neutrons with the I^{127} in the crystal. By reversing the scatterer and placing the lead against the crystal, the gamma radiation from the scatterer was absorbed and a background curve obtained. The difference between these two curves gave the gamma-ray spectrum from the scatterer. No accurate measurements of the energies of these gamma rays were made. Each gamma ray could be associated with a known nuclear level, however, and Fig. 1 shows a plot of peak position *versus* presumed photon energy.

Gamma-ray yields were obtained in the manner described by Guernsey.[4] The tungsten scatterers were all infinitely thick for the gamma rays produced in them. The crystal photopeak efficiency was taken proportional to the energy-dependent absorption probability of photons incident normally on 1-mm thick NaI.[5] The neutron flux was monitored by a Hanson long counter placed at 90° to the proton beam, and corrected for the angular distribution of the neutrons.[6] Corrections were made for internal conversion, using the data of Murray *et al.*[7] for W^{182} and W^{183}. Internal-conversion coefficients for the gamma rays from W^{184} and W^{186} were found by taking the coefficients for the various $E2$ transitions in W^{182} and W^{183}, and interpolating for other gamma-ray energies. The resultant gamma-ray production cross sections are only relative, since the absolute efficiency of the crystal was not measured.

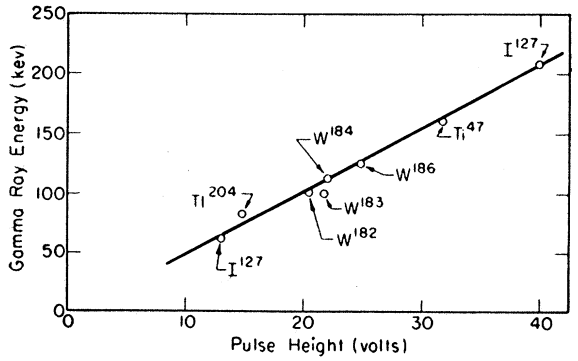

FIG. 1. Observed pulse height of total absorption peaks *versus* presumed gamma-ray energy for various isotopes, using the 1-mm thick crystal. Neutron energy = 1.00 Mev. The point marked "Tl^{204}" was obtained with x-rays from a source of that material.

[4] J. B. Guernsey and A. Wattenberg, Phys. Rev. **101**, 1516 (1956).
[5] "Cross Sections for Photon Interactions with NaI," Oak Ridge National Laboratory Drawing 9500 (unpublished).
[6] J. L. Fowler and J. E. Brolley, Jr., Revs. Modern Phys. **28**, 103 (1956).
[7] Murray, Boehm, Marmier, and DuMond, Phys. Rev. **97**, 1007 (1955).

TABLE II. Gamma radiation from monoisotopic scatterers.

Isotope	Gamma-ray energy (Mev)	Relative isotopic yield (normalized to the most intense gamma ray from each element)	Level assignment (0 = ground state, 1 = first excited state, etc.)	Energy from other work (Mev)	Reference
Ti^{46}	0.887±0.010	0.90 ±0.36	1→0	0.89	a
Ti^{47}	~0.160	...	1→0	0.160	a
	1.344±0.015	0.44 ±0.10	2→0 or 2→1	1.40 or 1.24	a
Ti^{48}	0.998±0.010	0.50 ±0.04	1→0	0.99	a
	1.329±0.010	0.087±0.012	2→1	1.33	a
	1.449±0.018	0.055±0.020	3→1	...	
Ti^{49}	None observed				
Ti^{50}	1.595±0.014	1.00 ±0.20	1→0	1.58	a
Cr^{50}	0.787±0.010	1.00 ±0.08	1→0	...	
Cr^{52}	0.960±0.020	0.044±0.010	2→1	0.94	a
	1.455±0.010	0.64 ±0.10	1→0	1.45	a
Cr^{54}	0.849±0.010	0.65 ±0.10	1→0	0.84	a
Ni^{60}	1.339±0.014	...	1→0	1.3325	a
Zn^{64}	~0.77	...	2→1	...	
	~1.00	...	1→0	1.00	a, b
Zn^{66}	0.836±0.012	0.60 ±0.10	2→1	...	
	1.051±0.010	1.00 ±0.12	1→0	1.04	a, b
Zn^{68}	0.821±0.012	0.38 ±0.12	2→1	0.81	a
	1.099±0.014	0.76 ±0.12	1→0	1.10	a
Ge^{70}	1.051±0.014	0.80 ±0.08	1→0	1.036	a
Ge^{72}	0.637±0.021	0.31 ±0.04	3→2	0.630	a, c, d
	0.840±0.013	0.97 ±0.09	2→0	0.835	a, c, d
Ge^{73}	None observed				
Ge^{74}	0.607±0.018	0.81 ±0.06	1→0	0.5963	a
	1.230±0.019	0.047±0.008	2→0	...	
Ge^{76}	0.560±0.020	1.00 ±0.10	1→0	0.566	a
Nb^{93}	0.521±0.010	0.52 ±0.10	...	...	
	0.759±0.010	0.95 ±0.06	...	...	
	0.971±0.010	1.00 ±0.09	...	...	
W^{182}	~0.100	See Fig. 2	1→0	0.10009	e
W^{183}	~0.099		2→0	0.09907	e
W^{184}	~0.112		1→0	0.112	f
W^{186}	~0.124		1→0	0.124	f

[a] Way, King, McGinnis, and van Lieshout, *Nuclear Level Schemes*, $A=40$—$A=92$, Atomic Energy Commission Report TID-5300 (U. S. Government Printing Office, Washington, D. C., 1955).
[b] C. E. Weller and J. C. Grosskreutz, Phys. Rev. **102**, 1149 (1956).
[c] Kraushaar, Brun, and Meyerhof, Phys. Rev. **101**, 139 (1956).
[d] Brun, Kraushaar, and Meyerhof, Phys. Rev. **102**, 808 (1956).
[e] Murray, Boehm, Marmier, and DuMond, Phys. Rev. **97**, 1007 (1955).
[f] McClelland, Mark, and Goodman, Phys. Rev. **93**, 904 (1954).

RESULTS

The energies and yields of the gamma rays observed from the monoisotopic scatterers are given in Table II, and those of the polyisotopic scatterers in Table III. These gamma rays are all assigned to neutron inelastic scattering. Some weakly excited gamma rays reported by other observers could not be detected with these small samples. The relative isotopic yield is normalized to the most intense gamma ray from each element. The assignments to excited states are also indicated in Tables II and III, and compared with the results of other experiments.

Figure 2 shows the relative cross section for production of gamma rays from the tungsten isotopes as a

TABLE III. Gamma radiation from polyisotopic scatterers.

Element	Gamma-ray energy (Mev)	Assignment Isotope	Assignment Transition	Energy from other work (Mev)	Reference
Cl	1.23±0.01	Cl^{35}	1→0	1.220	a, b
	1.77±0.01	Cl^{35}	2→0	1.762	a, b
Sr	0.88±0.01	Sr^{88}	2→1	0.909	c
	1.85±0.01	Sr^{88}	1→0	1.850	c
Nd	0.46±0.01	Nd^{146}	1→0	0.455	d
	1.60±0.02	Nd^{142}	1→0	1.576	e
Sm	None observed				
Gd	None observed				

[a] Van Patter, Swann, Porter, and Mandeville, Phys. Rev. **103**, 656 (1956).
[b] Endt, Paris, Sperduto, and Buechner, Phys. Rev. **103**, 961 (1956).
[c] Lazar, Eichler, and O'Kelley, Phys. Rev. **101**, 727 (1956).
[d] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **100**, 150 (1955).
[e] Jensen, Laslett, and Zaffarano, Phys. Rev. **80**, 862 (1950).

function of neutron energy. The curve for normal tungsten represents the production of gamma rays of energy 100 to 125 kev from the normal isotopic mixture, and was obtained by adding the curves for all isotopes weighted by the natural abundances.

DISCUSSION

Titanium

The assignments made in Table II for the gamma rays from the titanium isotopes agree with the previously-known excited states.[8] The 1.344-Mev gamma ray could be the second-to-ground state transition in Ti^{47} measured elsewhere as 1.40±0.08 Mev, or the second-to-first state transition of 1.24±0.08 Mev.[8] There was no indication in the present work of a second gamma ray 0.16 Mev higher or lower in energy.

The yields of the gamma radiation from the even-even first excited states are equal to within a factor of two. The 1.449-Mev gamma ray from Ti^{48} is assigned to the third-to-first state transition. Its yield is similar to that of the 1.324-Mev gamma ray, and it is unlikely that it comes from a state as high as 2.32+1.45=3.77 Mev, only 0.6 Mev below the neutron bombarding energy. This would require the third excited state to lie at 2.447 Mev. A reasonable assignment for this state is 2+ which would not be excited by the decay of Sc^{48} or V^{48}.[8] There is previous evidence for a state just above the 2.32-Mev level.[9]

Chromium

The gamma rays from Cr^{52} and Cr^{54} fit accurately into the known level schemes, and are assigned accordingly. The 0.787-Mev gamma ray, by analogy with the other two intense ones, is assigned to the decay of the first excited state of Cr^{50}, thus locating this level. This value is in keeping with the energies of the first levels of other even-even nuclei in the neighborhood of 28 neutrons.[10,11]

Nickel

An enriched Ni^{60} sample was made available recently. The direct observation of the 1.339-Mev gamma ray from it confirms the assignment made previously,[2] using Ni^{58} and normal nickel. The energy of this gamma ray was measured by alternate comparison with a Co^{60} source.

Zinc

Radiation of energy 0.825±0.010 Mev and 1.024 ±0.010 Mev was observed from a normal zinc scatterer. These energies correspond to the maxima of characteristic total-absorption peaks; both these peaks were composite, and each was caused by more than one gamma ray. The 1.024-Mev peak was too wide to be produced by a single gamma ray, and too low in energy to be due to the gamma rays observed from the Zn^{66} and Zn^{68} scatterers. [The half-widths of peaks from single gamma rays were measured from the interleaved calibration spectra, and interpolated by assuming a variation of resolution as (photon energy)$^{-\frac{1}{2}}$.] It is then due to an overlap of the 1.051- and 1.099-Mev gamma rays and roughly an equal amount of an ~1.00-Mev gamma ray from the first level in Zn^{64}.[8] The 0.825-Mev peak had a low-energy tail. After subtraction of the composite of the 0.821-Mev and 0.836-Mev radiation from Zn^{66} and Zn^{68}, a new photopeak at ~0.77 Mev remained, again due to Zn^{64}. The energy of these two gamma rays found by "unpeeling" could not

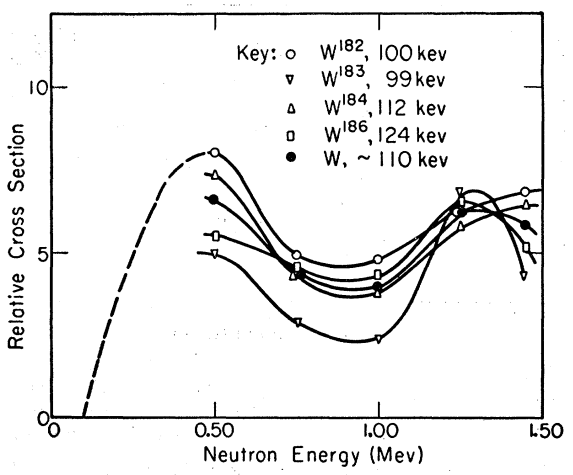

FIG. 2. Relative cross sections for production of the indicated gamma rays from the tungsten isotopes by fast neutrons *versus* neutron energy. The curve for normal tungsten was obtained by weighting each curve by its isotopic abundance and adding.

[8] Way, King, McGinnis, and van Lieshout, *Nuclear Level Schemes, A=40—A=92*, Atomic Energy Commission Report TID-5300 (U. S. Government Printing Office, Washington, D. C., 1955).
[9] Bretscher, Alderman, Elwyn, and Shull, Phys. Rev. **96**, 103 (1954).
[10] G. Scharff-Goldhaber, Phys. Rev. **90**, 587 (1953).
[11] P. Stähelin and P. Preiswerk, Nuovo cimento **10**, 1219 (1953).

be measured as accurately as that of the others, and these values are estimated to be accurate to only ± 30 kev.

The assignment of the two gamma rays from Zn^{68} agrees with the known[8] energy of the first two states. The 0.821-Mev transition has not been reported previously, although its excitation is energetically possible by orbital electron capture of Ga^{68}. The location of the Zn^{66} 0.836-Mev gamma ray as the second-to-first state transition, and the consequent placing of the second state at 1.887 Mev, are analogous to the results of Zn^{68}. Such a state, if it were 4+, would be only weakly excited in the decay of Cu^{66} and could have escaped previous detection.[8] The yield of the 0.77-Mev gamma ray is approximately equal to that of the 0.836- and 0.821-Mev gamma rays, and again by analogy it is assigned to the second-to-first state transition in Zn^{64}. This locates the second state at ~ 1.77 Mev. This is consistent with the data of Weller and Grosscreutz,[12] and requires only one change in their suggested level scheme for Zn^{64}. The ratio of the energies of the second to the first excited state of Zn^{68}, Zn^{66}, and Zn^{64} is then, respectively, 1.75, 1.80, and ~ 1.77.

Germanium

The isotopic assignments made by direct observation confirm those made previously from a study of normal germanium.[13] The level assignment of the most intense gamma ray from each isotope is straightforward, and is confirmed by the agreement with the results of other experiments. It should be noted that the present experiment could not detect the 0+ first state[8] of Ge^{72}. The excitation of the 2+ second state, however, is comparable to that of the 2+ first states in Ge^{70}, Ge^{74}, and Ge^{76}, even after allowing for the contribution to the 0.840-Mev gamma ray by the cascade from the third state.

The 0.637-Mev gamma ray from Ge^{72} is assigned to the third-to-second state transition. Studies of the decay of Ga^{72} [14] and As^{72} [15] have shown that the ratio of crossover to cascade radiation from the third state of Ge^{72} is 0.13. The yield of this 1.46-Mev crossover gamma ray in the present work should thus be $0.31 \times 0.13 \simeq 0.04$, and be comparable to that of the 1.230-Mev gamma ray from Ge^{74}. The latter gamma ray could be clearly detected, while no evidence for a 1.46-Mev gamma ray from Ge^{72} could be found. An upper limit of a quarter of the yield of the 1.230-Mev gamma ray can be placed on that of any 1.46-Mev radiation, giving an upper limit on the crossover/cascade ratio of 0.04, as measured by this experiment.

The assignment of the 1.230-Mev gamma ray to the second-ground state transition in Ge^{74} follows from the location of the corresponding states in nearby even-even nuclei.[16] The low yield of this gamma ray relative to the 0.607-Mev radiation suggests that this state decays more often by a 0.62-Mev gamma ray to the first state. The 0.607-Mev total-absorption peak in the pulse-height spectra, however, has the width and shape expected of a peak from a single gamma ray, determined by comparison with those from radioactive sources. This indicates that if it is caused by two gamma rays of nearly equal energy and comparable yield, these two are <30 kev apart in energy. Thus the presence of such a cascade cannot be proved or disproved from this work.

Niobium

No assignments are possible from present information for the niobium gamma rays, although it seems likely the 0.759-Mev and 0.971-Mev gamma rays are in 1:1 cascade.

The energy of the 0.521-Mev radiation was compared with that of annihilation radiation, and was consistently higher. This gamma ray could not be detected from the scatterer immediately after mechanical interruption of the deuteron beam, which sets an upper limit of $\frac{1}{4}$ sec on its half-life. Since no short-lived positron emitters can be made by 4-Mev neutron bombardment of Nb^{93}, it is concluded that this is a nuclear transition and not annihilation radiation.

Tungsten

The energies of the gamma rays from the tungsten isotopes were not measured accurately, but the various radiations can be associated with the excitation of known levels. It is of interest to note that the excitation curves for the various excited states, shown in Fig. 2, are very similar in both magnitude and shape. The minimum in the curves can be explained by competitive excitation of higher states; the subsequent rise at higher neutron energies is then due to the excitation of even higher states cascading to the lower levels. These results are in agreement with earlier work with normal tungsten,[4] although the minima in the yield curves is more pronounced in the present results.

A search for higher energy gamma rays showed that the previously reported[13] radiation of energy 0.64 and 0.77 Mev is due to neutron interactions in the iodine of the detecting crystal[17,18] and does not come from tungsten. In this earlier work[13] a "background" obtained with a carbon scatterer was subtracted from the tungsten data after normalization. The actual neutron spectrum entering the crystal from the tungsten scatterer was different from that from carbon, containing more low-energy neutrons which emphasized these gamma rays.[17]

[12] C. E. Weller and J. C. Grosscreutz, Phys. Rev. **102**, 1149 (1956).
[13] R. M. Sinclair, Phys. Rev. **99**, 621 (1955).
[14] Kraushaar, Brun, and Meyerhof, Phys. Rev. **101**, 139 (1956).
[15] Brun, Kraushaar, and Meyerhof, Phys. Rev. **102**, 808 (1956).
[16] G. Scharff-Goldhaber and J. Weneser, Phys. Rev. **98**, 212 (1955).
[17] R. B. Day, Phys. Rev. **102**, 767 (1956).
[18] J. J. van Loef, thesis, Utrecht, 1955 (unpublished).

Chlorine

The 1.23- and 1.77-Mev gamma rays from chlorine can be assigned by energy comparison as ground state transitions from the first two states of Cl^{35} at 1.220 Mev and 1.762 Mev, respectively.[19] A state in Cl^{37} has been reported at 1.713 Mev[20] or 1.728 Mev.[21] No evidence was found for a gamma ray of this energy on the low-energy side of the 1.77-Mev peak. This peak was symmetrical, and had a half-width equal within the error of measurement to that from the 1.71-Mev gamma ray from Sb^{124}. This sets an upper limit of $\sim 5\%$ of the intensity of the 1.77-Mev gamma ray on any 1.71-Mev radiation from normal chlorine, or $\sim 10\%$ on any 1.73-Mev radiation.

Strontium

Placing the 0.88-Mev gamma ray in cascade above the 1.85-Mev gamma ray agrees with the known level scheme of Sr^{88},[8] and the observation that the bombardment of strontium by 1.2-Mev neutrons produces no gamma rays.[18,22]

Iodine

The gamma rays from $I^{127}(n,n'\gamma)I^{127}$ were observed as background in the study of the tungsten isotopes. The yield of the 62-kev gamma ray was measured, and found to be essentially the same as reported previously.[4] The anomalous behavior of the 145-kev gamma ray reported elsewhere[18,22] was noted here: its yield increased as the neutron energy was reduced to 150 kev, so it must come from a process other than inelastic scattering.

Neodymium

The isotopic assignment of the two observed gamma rays was made on the basis of the previously known first excited states in Nd^{142} [23] and Nd^{146}.[24] Another isotope of approximately equal abundance is Nd^{144}, but the corresponding transition, known from beta decay to be 0.69 Mev,[25] could not be identified in these measurements.

[19] Van Patter, Swann, Porter, and Manderville, Phys. Rev. **103**, 656 (1956).
[20] Schiffer, Gossett, Phillips, and Young, Phys. Rev. **103**, 134 (1956).
[21] Endt, Paris, Sperduto, and Buechner, Phys. Rev. **103**, 961 (1956).
[22] J. J. van Loef and D. A. Lind, Phys. Rev. **101**, 103 (1956).
[23] Jensen, Laslett, and Zaffarano, Phys. Rev. **80**, 862 (1950).
[24] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **100**, 150 (1955).
[25] Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).

CONCLUSIONS

This work completes the study of the available even-even isotopes from $_{22}Ti$ to $_{32}Ge$, as well as $_{74}W$. The energies of the levels measured here agree in all cases with the values from other experiments. Where new levels have been found, their spins and parities can be estimated from the fact that they are not excited by other means, while the excitation by fast neutrons is not strongly dependent upon these parameters.

Certain regularities are now apparent in the results. First, the new levels fit into the systematic pattern reported elsewhere.[10,11] Secondly, the excitation of the first excited state of the several even-even isotopes of each element is surprisingly uniform. The greatest difference occurs in the titanium isotopes, where there is a factor of 2 between Ti^{48} and Ti^{50}. The validity of the measurements is limited because of the question of cascade *versus* crossover transitions from the higher states, but this will not change the observed excitations markedly.

The only noticeable disagreement between this work and other experiments occurs in the cascade structure of Ge^{72}, as previously discussed. (Another discrepancy, discussed fully in a previous publication,[2] occurs in Te^{126}.)

Future work by this method can be done as more separated isotopes become available. The regions of the periodic table at or near magic proton or neutron numbers, where the first few levels are high and widely spaced, can be studied by the use of the first experimental method described here. In other regions of low excited states, the thin-crystal technique would be more useful.

ACKNOWLEDGMENTS

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