TABLE III. Table of resonance integral calculations, in barns.

	Present work	General Atomic	Harwell
I Resolved resonance region	62.78 (0.5–70 eV)	71.88 (0.5–222)	71.22 (0.5–866 eV)
II Columbia data to 4000 eV	18.34 (70–4000 eV)	8.16 (222–4000 eV)	1.70 (866–4000 eV)
III Unresolved *S*-wave contribution above 4000 eV	1.0	1.0	1.0
IV *P*-wave contribution	1.2	1.2	1.2
V $1/v$ contribution	3.0	3.0	3.0
Totals	86 ± 6	85.2	78.2

half of the resonance integral is contributed by the first three resonances in thorium and 80% by the resonances below 200 eV.

(1) The presently reported results are combined with the Columbia results from 100 to 4000 eV to calculate the resonance integral. A $\langle\Gamma_\gamma\rangle$ of 20 meV is assumed.

(2) The Harwell results are combined with Columbia results above 866 eV.

(3) The General Atomic data are combined with Columbia data above 222 eV.

In each instance the Columbia data is used to 4000 eV. Above that energy the integrated expressions (10) and (11) are used to provide corrections.

The results are listed in Table III. The resonance integral has been computed using the quoted parameters for Γ_n and Γ_γ. Where Γ_γ has not been measured, an average value of Γ_γ as measured in the *same experiment* has been used (e.g., $\langle\Gamma_\gamma\rangle = 19$ meV for the Columbia high-energy data). Of course, any value of the resonance integral may be obtained by an arbitrary choice of an average Γ_γ. This, however, leads, in general, to an inconsistent set of Γ_n and Γ_γ for a measured resonance and so we must reject this procedure.

The higher values obtained for the BNL data arise from the higher values for the neutron widths of the first two resonances.

ACKNOWLEDGMENTS

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Neutron-Capture Gamma-Ray Studies in Isotopes of Tungsten

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γ-ray spectra from a natural-tungsten target following the capture of 0.06-eV neutrons and neutrons corresponding in energy to the lowest-energy resonances in W^{182}, W^{183}, and W^{186} have been obtained at high resolution using a lithium-drifted germanium detector. Transitions have been identified which take place from the capture states to states near ground states in the final nuclei. Low-lying states previously known have been observed and several new states have been identified. Precise energy values and approximate relative intensities of the transitions are given.

I. INTRODUCTION

THE recent availability of large lithium-drifted germanium detectors has prompted intensive reexamination of neutron-capture γ-ray experiments. Resolution of the order of 6–10 keV is attainable for 6-MeV γ rays using commercially available detectors and electronics. This resolution is more than an order of magnitude better than that attainable with NaI(Tl), and is sufficient to fully resolve most transitions from a capturing state at 5–8 MeV to levels of low excitation in the final nucleus, even in the heavy elements. Therefore a great deal of valuable information can be obtained by utilizing these new detectors in studies of the high-energy γ rays which are emitted following neutron capture in individual resonances of medium- and heavy-mass target nuclei. It has been shown by Wasson *et al.* that Ge(Li) capture γ-ray spectra can be obtained with a thermalized flux of neutrons from Pu-Be sources,[1] and in both the thermal and the resonance-energy region with neutrons produced by a linear accelerator.[2] These same kinds of experiments should also be possible using a facility with low γ-ray and low fast-neutron backgrounds, incorporating the "through" hole in the Materials Testing Reactor. The present studies were done in part to verify that the neutron flux from this facility is sufficient to investigate resonance neutron-capture γ-ray spectra with a germanium detector. The target for these initial studies was chosen with the idea of thoroughly testing the capabilities of the apparatus. A natural-tungsten target seemed to meet this requirement. Naturally occurring tungsten consists of several isotopes with roughly equal abundances. Three of these isotopes have at least one low-lying

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

[1] O. A. Wasson, K. J. Wetzel, and C. K. Bockelman, Phys. Rev. **136**, B1640 (1964).

[2] K. J. Wetzel, O. A. Wasson, and C. K. Bockelman, Bull. Am. Phys. Soc. **10**, 13 (1965).

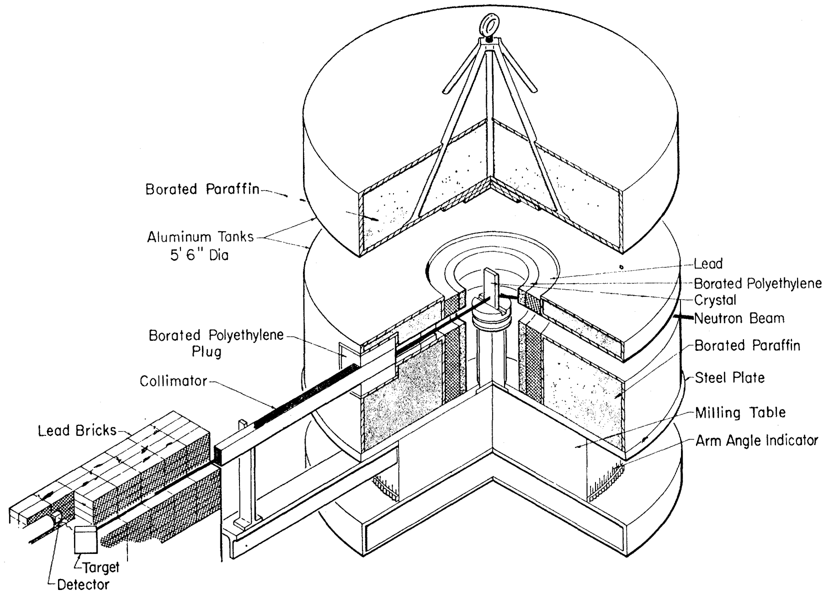

FIG. 1. The neutron monochromator and experimental arrangement.

neutron resonance. Previous NaI(Tl) results[3] indicate that the tungsten-capture γ rays have moderate to weak intensities. In addition, tungsten is in a region of highly deformed nuclei where low-lying level structure is well described by the model proposed by Bohr and Mottelson[4] and by Nilsson.[5]

II. APPARATUS

The primary beam used in these experiments is produced by scattering from a 2 in. thick water sample placed in the HT-1 horizontal through hole of the Materials Testing Reactor.[6] Monochromatic neutrons with energies up to 20 eV are provided by Bragg diffraction from various planes of a beryllium crystal. Figure 1 shows a sketch of the experimental arrangement. A 1 in. by $\frac{3}{4}$ in. primary beam enters the crystal shielding through a 60° slot and strikes the beryllium crystal. The primary beam intensity at this point is approximately 7×10^8 neutrons/cm^2 sec. The undiffracted beam is stopped in a Li^6-carbonate slab backed by lead. The crystal is surrounded by 2 in. of borated polyethylene, 4 in. of lead and a 2-ft thick annular tank filled with boric acid in paraffin. The Bragg beam exits through a borated polyethylene plug in the shielding into which is inserted a 2-min divergence Soller slit collimator. The Bragg beam then enters the target area through a 2-in.$\times$2-in. hole in the lead shielding surrounding the detector. The entire crystal shielding assembly and arm are mounted on a large motor-driven milling table. The beryllium crystal is mounted on an independently driven goniometer, which is adjusted to the desired angle setting after the arm angle is selected with the milling table. A vernier scale on the table base allows the arm angle to be read to within 1 min of arc. The crystal angle is indicated to 0.1° on an electronic readout and "rocked in" to a more precise energy by maximizing the Bragg neutron flux indicated by a He^3 neutron counter.

Borated polyethylene blocks lined with Li^6 carbonate define the Bragg beam to a diameter of 1 in. near the target. In these experiments a 0.1-in. thick sheet of natural tungsten was placed in the beam at an angle of about 45° to the beam. The germanium detector, at 90° to the beam, was then placed as near the target as possible without intercepting the neutrons. A Li^6-carbonate shield was placed between the target and the detector in order to reduce the effect of scattered neutrons on the detector. The detector is a Ge(Li) diode made by RCA of Canada Ltd. Its active volume is 2.0 cm^3.

The electronics associated with the γ-ray detector consisted of a Tennelec 100 C pre-amplifier, Ortec 410 main amplifier, Ortec 408 biased amplifier, Ortec 411 pulse stretcher, and TMC 1024 channel analyzer. γ rays from about 4 to 7.5 MeV were recorded at each neutron energy.

III. CALIBRATION

A convenient γ ray for energy calibration is provided by the reactor itself. Cooling water for the beam-hole plug is activated by means of the $O^{16}(n,p)N^{16}$ reaction in the region near the reactor core. The subsequent decay of N^{16} in the coolant pipe at the reactor

[3] L. V. Groshev, A. M. Demidov, V. N. Lutsenko, and V. I. Pelekhov, in *Atlas of γ-Ray Spectra From Radiative Capture of Thermal Neutrons* (Pergamon Press, Inc., New York, 1959).

[4] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. **27**, No. 16 (1953).

[5] S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. **29**, No. 16 (1955).

[6] R. M. Brugger, Nucl. Instr. Methods **32**, 303 (1965).

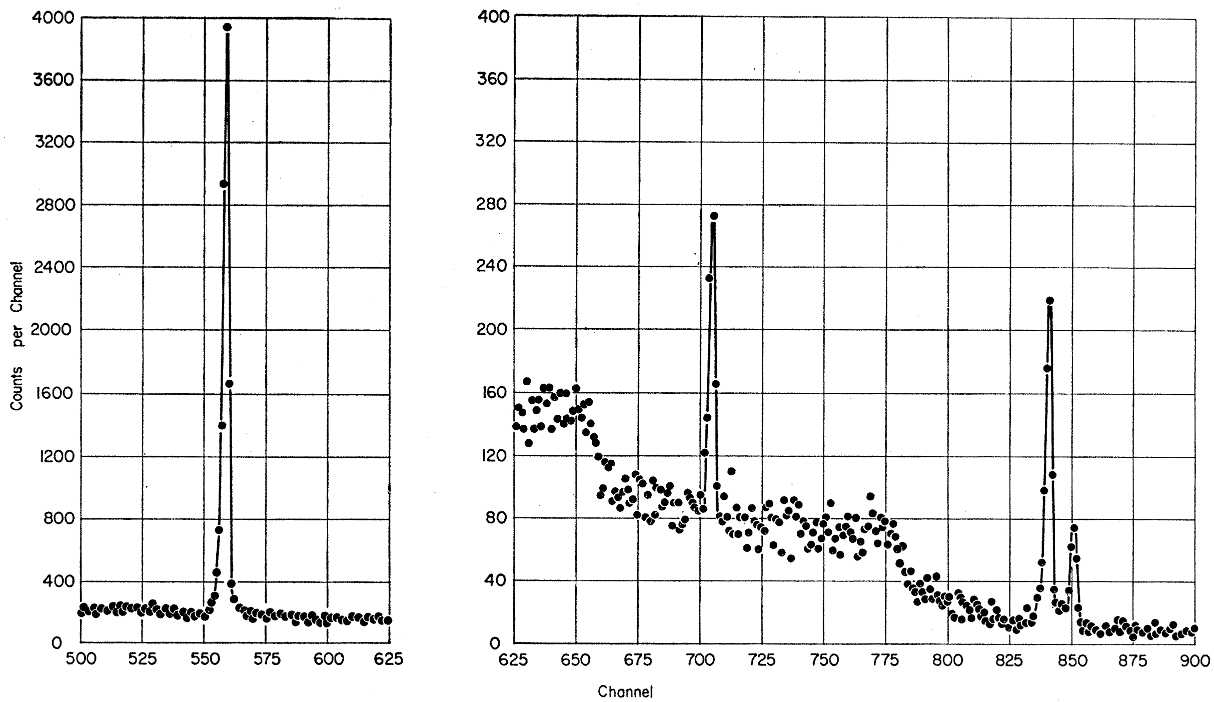

FIG. 2. Spectrum of the O^{16} γ ray used for energy calibration of the detector system.

face provides a source of 6-MeV γ rays. The γ ray of interest has a reported energy[7] of 6127.8±1.2 keV. By unshielding the detector and the cooling-water line the double-escape, single-escape, and full-energy peaks of this γ ray may all three be observed in about one hour. Since the double-escape to photopeak energy difference is known within a few eV, this gives the energy per channel to an accuracy dependent only on ability to pick the peak centers. The system linearity was periodically determined with a precision pulser and a correction curve was derived. It was assumed that the peak centers could be picked to $\pm\frac{1}{2}$ channel including any error in linearity correction. This indicates uncertainties in energy ranging from ±2.5 to ±4.5 keV for the γ rays observed in these experiments. Energy differences among various γ rays are actually more precise than this, since the ±1.2-keV error in the O^{16} γ-ray energy does not contribute to the error in these differences. Figure 2 shows a typical calibration spectrum. The double-escape peak from the 6128-keV γ ray occurs in channel 558.8, the single-escape peak in channel 704.6, and the full-energy peak in channel 850.4. In addition, 20% of the N^{16} decay proceeds to an excited level in O^{16} at about 7.1 MeV. The double-escape peak in channel 840.7 corresponds to the

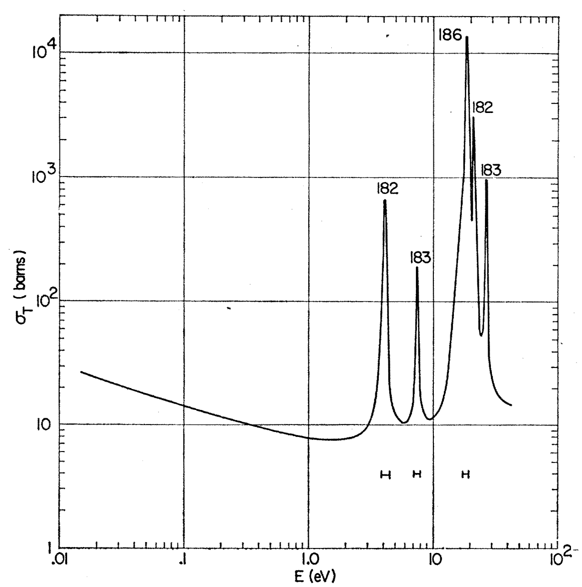

FIG. 3. Low-energy neutron cross section of tungsten showing monochromator resolution.

TABLE I. Abundances and thermal-neutron absorption cross sections of W isotopes according to Ref. 8.

Isotope	Abundance (%)	σ_{ABS}(0.025 eV) (barns)
180	0.14	<20
182	26.41	20±2
183	14.40	11±1
184	30.64	2±0.3
186	28.41	35±3

[7] R. E. Berg and E. Kashy, Nucl. Instr. Methods **39**, 169 (1966).

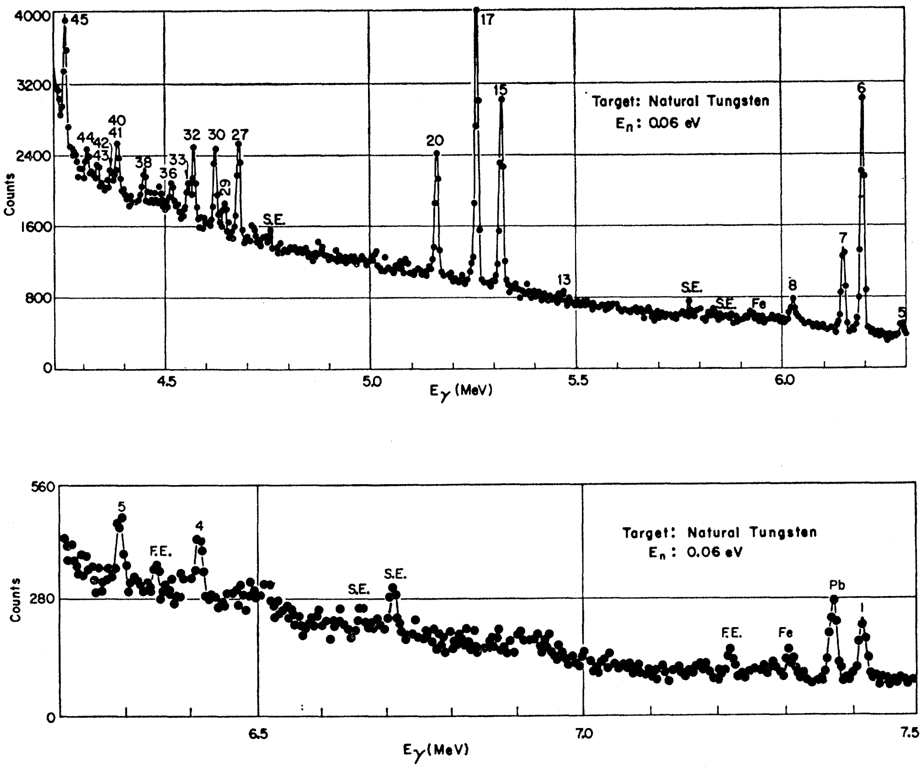

FIG. 4. High-energy tungsten γ rays following capture of 0.06-eV neutrons.

de-excitation of this excited level to ground. These data yield a γ-ray energy of 7114.1 keV for this transition. With addition of the nuclear recoil energy, the excitation energy of the corresponding O^{16} level is found to be 7115.8±2.8 keV.

The relative efficiency as a function of energy for the detector was determined in the region of interest in the present experiments by comparing chlorine-capture γ-ray peaks with the relative intensities quoted by Wasson.[1] A relative efficiency curve was plotted from 4 to 7.5 MeV and was used to correct the relative intensities of the observed γ rays from tungsten. Because of the uncertain geometry of the target-detector system and uncertainties in the chlorine relative intensities, the derived relative intensities quoted here for the tungsten γ rays are expected to be only approximate.

IV. DATA

Natural tungsten occurs as five stable isotopes only one of which, W^{180}, has a small abundance. Table I lists the abundance and thermal absorption cross section of each isotope as given in Nuclear Data.[8] It is evident that a thermal-energy neutron capture γ-ray spectrum from a natural tungsten target will contain γ rays from W^{183}, W^{187}, and probably to a lesser extent from W^{184}. In order to make isotopic assignments for observed γ rays it is necessary to have large quantities of enriched isotopes for thermal capture, or, it is possible to use a natural target and observe the γ rays following capture of neutrons in individual resonances. In the present experiments γ-ray spectra from W^{183}, W^{184}, and W^{187} were obtained separately with a natural target by using neutrons of energies corresponding to the 4.1-eV resonance of W^{182}, 7.6-eV resonance of W^{183}, and 19-eV resonance of W^{186}, respectively. In order to give an idea of the extent to which resonances were isolated with the monochromator, the low-lying neutron cross section of tungsten has been reproduced from BNL-325[9] in Fig. 3 with isotopic assignments and the estimated neutron resolution (full width at half-height) at each resonance. The neutron resolution is represented by bars in the energy regions at which spectra were taken. The Be $(10\bar{1}1)$ planes were used as the monochromator for the 0.06-, 4.1-, and 7.6-eV data. The Be $(10\bar{1}3)$ planes were used for the 19-eV data. The angular resolution at 0.06 eV is determined by the 7-min critical angle for total reflection of the nickel collimator at this energy, and 6-min mosaic spread of the beryllium crystal. The energy resolution was then computed from the angular resolution, and d spacing of the crystal planes, and the Bragg angle. At the higher energies the angular resolu-

[8] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington 25, D. C.), NRC00-000-00, Sec. B, Nos. 1 and 2 (1966).

[9] *Neutron Cross Sections*, compiled by D. J. Hughes and R. B. Schwartz (U. S. Government Printing Office, Washington 25, D. C.), BNL-325.

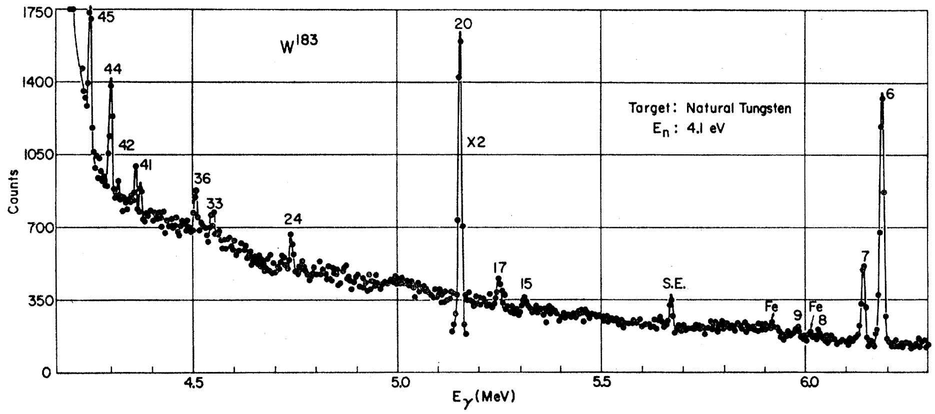

FIG. 5. High-energy W^{183} γ-ray spectrum from capture of 4.1-eV neutrons.

tion is determined primarily by the 6-min mosaic spread. Due to the use of a 2-min divergence Soller slit collimator little effect is from incident beam divergence, and it has been neglected for the estimates in Fig. 3. A cadmium filter was inserted in the reactor beam for all of the resonance-energy measurements.

Figure 4 shows the spectrum of γ rays taken with 0.06-eV neutrons incident on the natural-tungsten target. The running time was 66 h. This neutron energy corresponds approximately to the peak of the reactor Maxwellian flux distribution and the resulting γ-ray spectrum is expected to be representative of low-energy off-resonance capture. In this spectrum and in all succeeding spectra, the γ-ray energy scale has been adjusted so that the double-escape peaks appear at the full γ-ray energy. Single-escape peaks are labeled S. E. and full-energy peaks F. E. in the figures. Known background effects are labeled with the chemical symbol for the element responsible. The major sources of background in these spectra are from neutron capture in iron and from the beam-hole plug-cooling water activity.

Figure 5 is the spectrum of γ-rays taken with 4.1-eV neutrons incident on the natural-tungsten target. The running time was 90 h. A number of peaks in Fig. 5 are observed which correspond energetically to peaks in Fig. 4. Although the 4.1-eV spectrum is not shown above 6.3-MeV γ-ray energy, no additional tungsten γ rays were observed up to 7.6-MeV γ-ray energy.

Table II lists the energy, estimated error in energy, final-state energy, and approximate relative intensity of γ rays assigned to W^{183} from the data of the two preceding spectra. In deriving the final-state energy, it was assumed that all the observed γ rays correspond to primary transitions from the capturing state. This may not be a good assumption for some weak γ rays at the lower energies in these spectra.

The high-energy neutron capture γ-ray spectrum of W^{184} was studied by using incident neutrons with energy corresponding to the first resonance of W^{183} at 7.6 eV. The spectrum obtained after 73-h running time is shown in Fig. 6. A few of the more intense transitions

TABLE II. γ rays from W^{183}.

Peak No.	E_γ (keV)	Estimated error (keV)	Excitation energy (keV)	I/E^3 Approximate reduced relative intensity 0.06 eV	4.1 eV
6	6191	2.5	0	100	100
7	6144	2.5	47	36	32
9	5983	3	208	···	2
20	5163	3	1028	81	343
24	4751	3.5	1440	···	20
33	4558	4	1633		
36	4516	4	1675	···	21
41	4378	4	1813	···	11
42	4363	4	1828	···	17
44	4301	4	1890	18	96
45	4246	4	1945	103	84

TABLE III. γ rays from W^{184}.

Peak No.	E_γ (keV)	Estimated error (keV)	Excitation energy (keV)	I/E^3 Approximate reduced relative intensity 0.06 eV	7.6 eV
1	7413	3.5	0	100	100
2	7302	3.5	111	···	9
3	6508	3.5	905	···	9
4	6409	3.5	1004	82	71
5	6290	3.5	1123	98	70
8	6026	3.5	1387	187	30
9	5983	4.0	1430	···	6
10	5781	4.0	1632	···	8
11	5639	4.0	1774	···	36
12	5603	4.5	1810	···	9
14	5352	4.0	2061	···	37
16	5288	4.0	2125	···	47
18	5246	4.0	2167	···	31
19	5169	4.0	2244	···	38
21	4906	4.5			
22	4862	4.5			
23	4767	4.5			
25	4724	4.5			
26	4709	4.5			
28	4657	4.5			
29	4646	4.5			
31	4615	4.5			
35	4524	4.5			
37	4466	4.5			

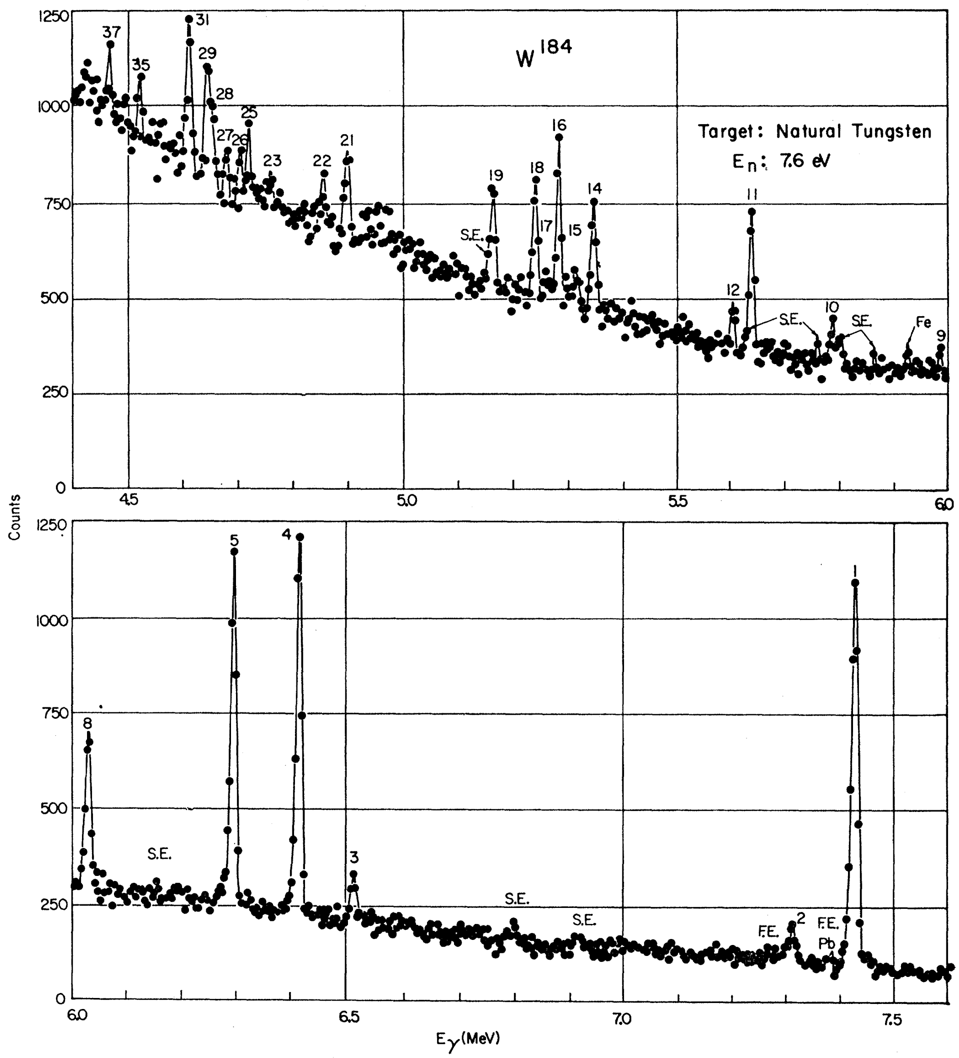

FIG. 6. High-energy W^{184} γ-ray spectrum from capture of 7.6-eV neutrons.

assigned to W^{184} from the data of this figure also appear weakly in the 0.06-eV spectrum (Fig. 4). Peaks 1, 4, 5, and 8 in Fig. 4 correspond in energy to peaks with the same numbers in Fig. 6 and are assigned to W^{184}. The γ-ray energies, estimated error in energy, corresponding energies of excitation in W^{184}, and E^3-reduced relative intensities of the W^{184} γ rays derived from the 7.6-eV data are given in Table III.

Figure 7 is the γ-ray spectrum observed with 19-eV neutrons incident on the target. The running time was 162 h. It is evident that peaks 15 and 17 in this and in previous spectra may be assigned to transitions in W^{187}. Peaks 27, 30, and 32 are also assigned to W^{187}. Peaks 38, 39, and 40 are very weak and permit only tentative assignment to this isotope. Table IV gives the derived γ-ray energies, estimated error in energy, excitation energy of the corresponding final state (assuming all transitions observed to be primary transitions) and the E^3-reduced relative intensities of the γ rays assigned to W^{187} from these data. It should be noted that γ rays corresponding in energy to peaks 15 and 17 also appear weakly in the 4.1-eV spectrum. This is probably due to a small cross-section component at 4.1 eV from the wing of the 19-eV resonance and, hence, to capture in W^{186}.

TABLE IV. γ rays from W^{187}.

Peak No.	E_γ (keV)	Estimated error (keV)	Excitation energy (keV)	I/E^3 Approximate reduced relative intensity 0.06 eV	19 eV
13	5465	4	0	2	5
15	5318	3	147	63	53
17	5260	3	205	100	100
27	4681	4	784	44	21
30	4623	4	842	32	22
32	4572	4	893	26	12
38	4446	4	1019		
39	4405	4	1060	...	
40	4380	4	1085		

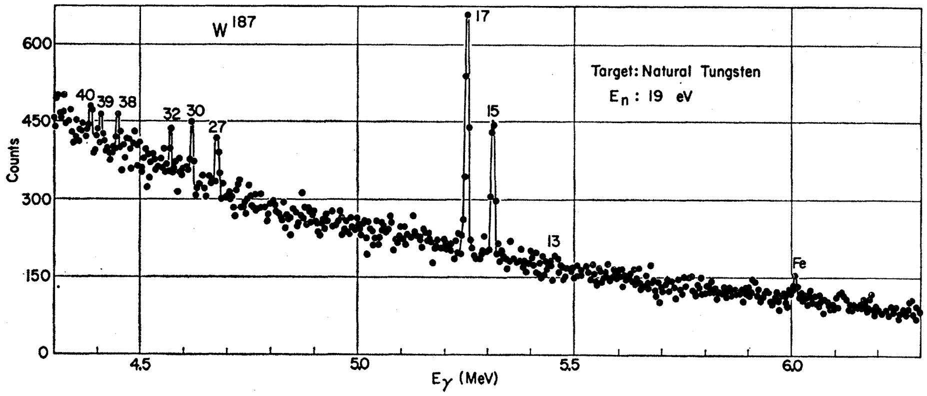

FIG. 7. High-energy W^{187} γ-ray spectrum from capture of 19-eV neutrons.

V. DISCUSSION: W^{183}, W^{187} γ Rays

In the even-even isotopes W^{182} and W^{186} the compound state formed by capturing an *s*-wave neutron must have spin and parity $\frac{1}{2}^+$. Since the de-excitation of the high-energy compound state to states near ground is expected to proceed predominantly with the emission of electric dipole radiation, the high-energy γ rays observed in the present experiment in most instances represent transitions to final states with spin and parity $\frac{1}{2}^-$ or $\frac{3}{2}^-$. Three such low-lying excited states have been assigned in W^{183}. These were deduced from studying the decay of Ta^{183} and Re^{183}, the results of which are summarized in Nuclear Data.[8] The ground state of W^{183} and the first excited state at 46.5 keV with spins $\frac{1}{2}$ and $\frac{3}{2}$, respectively, have been identified as the first two members of the $\frac{1}{2}^-$ [510] rotational band. An excited state at 208.8 keV of spin $\frac{3}{2}$ has been identified as the $\frac{3}{2}^-$[512] Nilsson state.[8] Below 500 keV, other higher-spin rotational members of these two bands have been assigned in addition to members of the $\frac{9}{2}^+$[624] and $\frac{7}{2}^-$[503] bands, none of which would be expected to be populated by primary transitions in the present experiments. The $W^{182}(d,p)W^{183}$ reaction data have been reported by Erskine.[10] A number of additional levels above 500-keV excitation were populated in the (d,p) studies.

The structure of low-lying excited states in W^{187} is less clear, since there is no available nucleus which decays to W^{187}. However, Erskine[10] has studied the $W^{186}(d,p)W^{187}$ reaction and has identified a few members of the same rotational bands that occur in W^{183}. The ground state of W^{187} has spin and parity $\frac{3}{2}^-$ and has been identified as the $\frac{3}{2}^-$[512] Nilsson state.[8] The $\frac{3}{2}$, $\frac{1}{2}^-$[510] state was identified in the (d,p) experiment at 205 keV. However, the $\frac{1}{2}$, $\frac{1}{2}^-$[510] state was not to be expected, and was not observed in the (d,p) study. The excitation energy of this level was calculated to be about 149 keV from the energy spacings of other members of the rotational band.[10] This is in good agreement with the value 147 keV computed from the energy of the 5318-keV W^{187} γ ray observed in the present work, assuming that the 5260-keV γ ray is a transition to the 205-keV state.

Figure 8 shows the energy levels in W^{183} and W^{187} derived from the (n,γ) data compared with those derived from the (d,p) results.[10] The (n,γ) reaction can be assumed to select only those states with spins of $\frac{1}{2}$ or $\frac{3}{2}$, and predominantly those with negative parity. Therefore these data are complementary to the (d,p) results, particularly for the higher excited states where the (d,p) data yield uncertain spin assignments. In general the (n,γ) results are in good agreement with the (d,p) data although transitions to a few new levels are apparently observed in the (n,γ) experiment.

Of interest in these data is the increase in the relative intensities of peaks 20, 44, and probably 24 compared to the other peaks in the 4.1-eV W^{183} spectrum when compared to the data at 0.06 eV. At the latter energy the cross-section contribution from the 4.1-eV resonance is 40%. The next two resonances contribute an additional 20%, leading to the conclusion that one or more resonances below the neutron binding energy must account for the balance of the cross section. With at least four resonances contributing to the capture γ-ray spectrum at 0.06 eV, one might expect that the relative intensities of the peaks would bear little similarity to the relative intensities at any one resonance. What is observed, however, is that the ratio of population of the ground state to that of the first excited state is the same within experimental error at 0.06 eV and at the resonance. On the other hand, the intensities of the transitions represented by peaks 20 and 44 increase relative to the ground-state transition by factors of 4.2 and 5.3, respectively, at the resonance compared to the 0.06-eV data. There are three possible interpretations of the lack of change in relative populations of the ground and first excited states. One is led to conclude that all resonances of significant size near the neutron-binding energy either (1) populate the ground and first excited states with the same relative intensity ratio, (2) populate these two states very weakly except for the 4.1-eV resonance, or (3) sum together in a

[10] J. R. Erskine, Phys. Rev. 138, B66 (1965).

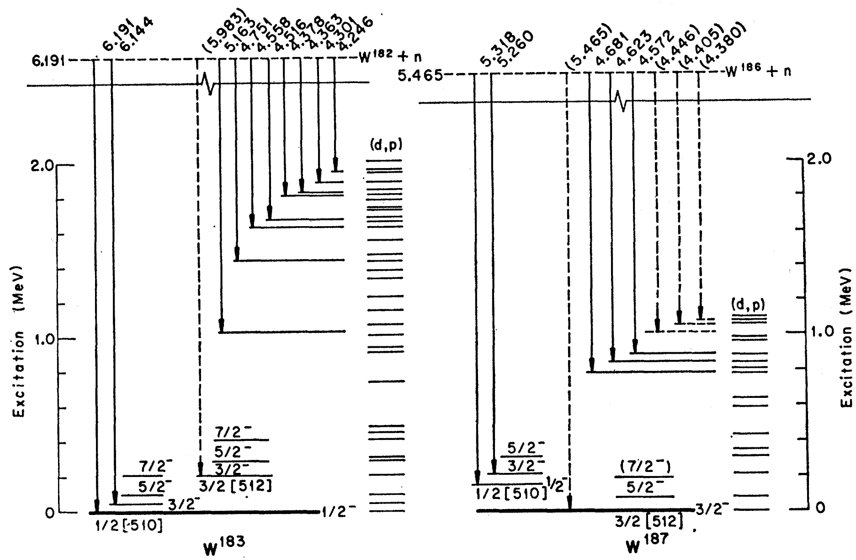

FIG. 8. Comparison of the W^{183} and W^{187} level schemes derived from (n,γ) and (d,p) experiments.

fortuitous manner to retain the observed constant ratio. It is also surprising that the transition to the $\frac{3}{2}^-[512]$ level is not observed at 0.06 eV and is only very weakly observed at 4.1 eV.[11]

In the case of W^{187}, the cross section at 0.06 eV is entirely accounted for by the strong 19-eV resonance. No significant difference in relative intensities is expected at the two neutron energies and none is observed. The transition to the $\frac{3}{2}^-[512]$ ground state of W^{187} is very weak in both spectra.

VI. DISCUSSION: W^{184} γ RAYS

Since the spin and parity of W^{183} is $\frac{1}{2}^-$, low-energy neutron capture can lead to compound states of 0^- and 1^-. The first three resonances are known to be 1^- states[8] and their decay will therefore populate directly states of spin 0, 1, and 2 with a preference for positive parity states due to the expected predominance of E1 over $M1$ transitions. At 0.06 eV about $\frac{1}{2}$ of the cross section is accounted for by the first three resonances at neutron energies of 7.62, 27.13, and 46.6 eV.

The low-energy states in W^{184} are well known from extensive radioactive decay studies. The states are populated in the decay of $Ta^{184}(5^-)$, and two isomers of $Re^{184}(3^-$ and $8^+)$. States thus populated are known up to about 1.5 MeV above ground. These data are summarized in Nuclear Data.[8] Known states which are expected to be seen from primary population by (n,γ) reactions at low energy are the 0^+ ground state, its 2^+ rotational state at 111 keV, and the 2^+ γ-vibrational band-head state at 904 keV. These transitions have been observed in previous NaI(Tl) capture γ-ray work.[8] The ground-state transition, peak 1, is clearly observed in our spectrum obtained with 0.06-eV neutrons as seen in Fig. 4. Two other peaks, Nos. 4 and 5, are also due to transitions in W^{184}. Figure 6 shows the γ-ray spectrum obtained by irradiation with neutrons corresponding to the 7.6-eV resonance in W^{183}. Here the three expected transitions, peaks 1, 2, and 3, are clearly observed. Several other transitions are also seen, some of which are rather intense. Of particular interest are the strong peaks, 4 and 5, which correspond to transitions populating states at 1004 and 1123 keV. Neither of these states has been observed in radioactive-decay studies. Energetically, decay to these states could take place from states in Re^{184} and Ta^{184} of spins 3^-, 8^+, or 5^-; therefore, it seems likely that these two states in W^{184} have low spin values, necessitating large spin changes if they are to be directly populated in radioactive decay. Since 0^+ states are frequently observed near 1 MeV in nearby even-even nuclei, it is suggested that these may both be 0^+ states. Further experimental work to determine their spins is in progress.

Peak 8 is apparently a transition to a state at 1387 keV seen by previous investigators[8] and also seen in radioactive decay.[12] Peak 9, from a 5983-keV γ ray, probably populates a state in W^{184} at an excitation energy of 1430 keV. Possibly this is the state previously reported[8] at 1426 keV. It should be noted that this γ ray corresponds exactly in energy to a transition in W^{183}, but since it was seen only very weakly if at all in W^{182} resonance capture, it seems likely that the two transitions do exist with very nearly equal energies. Other γ rays are seen in this spectrum, some of which have been previously reported.[8] Our proposed energy-level diagram[13] is shown in Fig. 9.

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[11] R. R. Spencer, K. T. Faler, and D. R. Dixon, Bull. Am. Phys. Soc. **11**, 336 (1966).

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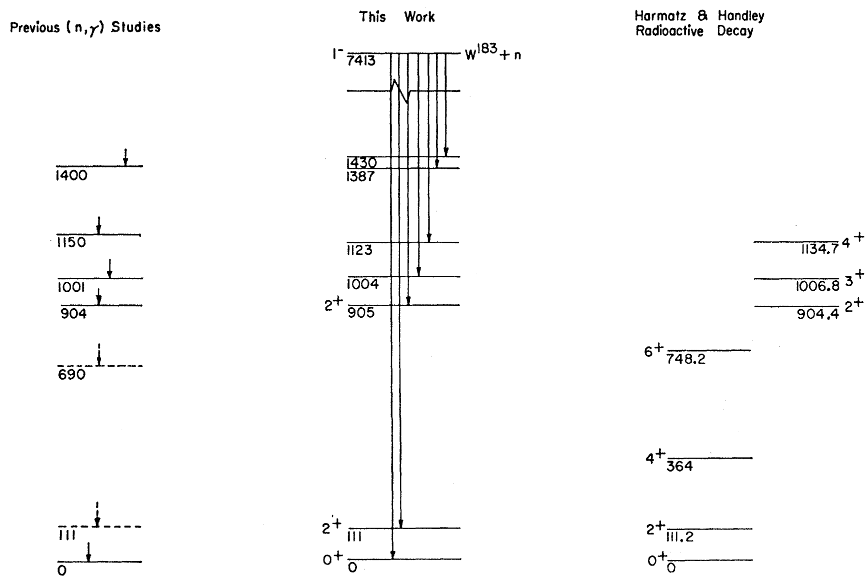

FIG. 9. Energy-level diagram of W^{184} derived from the present (n,γ) results.

VII. CONCLUSIONS

The first study with the new low-background neutron facility at the MTR has demonstrated that the technique of capture γ-ray studies at discrete neutron resonances is a particularly useful approach to studies of nuclear structure. Details of low-energy excited-state structure are observed which complement other methods such as radioactive decay and charged-particle reaction spectroscopy. In addition it is possible to obtain data on the neutron-capture process itself. Where previous studies have of necessity shown only gross statistical properties of the capture process, the technique used here permits one to observe depopulation of capture states with considerable selectivity. If systematic effects occur in the capture de-excitation process, continued experiments of this kind should allow them to be identified as more data become available.

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