New neutron-rich isotope: ^{190}W†

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A new neutron-rich isotope, ^{190}W, was produced by $^{192}Os(n,2pn)^{190}W$ (25–200-MeV neutrons) and by $^{192}Os(p,3p)^{190}W$ (92-MeV protons). Chemically separated sources were used to study its β and γ decay and the following characteristics were observed: $T_{1/2} = 30.0 \pm 1.5$ min; $E_\beta = 0.95 \pm 0.07$ MeV; $E_\gamma = 157.6$ and 162.1 keV. A decay scheme for ^{190}W is proposed based on the experimental data and on theoretical predictions for the excited level structure of ^{190}Re. A Q_{β^-} of 1.27 MeV was inferred from β-γ coincidence measurements.

[RADIOACTIVITY ^{190}W [from $^{192}Os(n,2pn)$, $^{192}Os(p,3p)$]; measured $T_{1/2}$, E_β, E_γ, I_γ, $\beta\gamma$ coin; deduced log*ft*, ICC, multipolarities. ^{190}Re deduced levels, J, π, Nilsson assignments. ^{190}Re calculated theoretical level structure. Enriched targets, radiochemistry, Ge(Li) detectors.]

I. INTRODUCTION

In recent years a number of medium energy facilities (i.e., the Brookhaven 200-MeV proton linac and the Los Alamos 800-MeV accelerator) have been used to produce new neutron-rich nuclei through such nuclear reactions as $(p,3p)$.[1,2] More recently, the medium energy intense neutron (MEIN)[3] facility at BNL has been used to discover[4] the new nuclide ^{62}Fe through the $(n,2pn)$ reaction with neutrons in the 25–200-MeV energy range. The present study reports the discovery of 30.0-min ^{190}W produced by both the $(p,3p)$ and $(n,2pn)$ reactions on enriched ^{192}Os targets. A decay scheme is proposed based on γ-ray and β-γ coincidence measurements and supported by theoretical predictions of the excited level structure of odd-odd ^{190}Re.

II. EXPERIMENTAL TECHNIQUES AND RESULTS

Sources of ^{190}W were produced via the $^{192}Os(n,2pn)$ and $^{192}Os(p,3p)$ reactions by the irradiation of isotopically enriched (98%) ^{192}Os metal with medium energy (25–200 MeV) neutrons and 92-MeV protons, respectively. The proton irradiations were carried out with about 10-μA beams from the Brookhaven linac injector of the alternating gradient synchrotron (AGS). Neutron irradiations were performed in the MEIN facility[3] which produced a neutron flux (25–200 MeV) of $\approx 1.0 \times 10^{11}$ n/cm^2 sec on target. Tungsten was chemically separated from irradiated ^{192}Os targets in the following manner: (1) ^{192}Os metal targets (10–20 mg) were dissolved in a minimum amount of 30% H_2O_2-H_2SO_4; (2) OsO_4 was distilled at ≈ 110°C in the presence of W carrier into an iced 6 *N* NaOH trap; (3) the precipitated tungstic acid was washed with warm dilute nitric acid; (4) the precipitate was dissolved in a minimum amount of concentrated NH_4OH; (5) Re and Ta were scavenged as oxides; (6) the supernate was heated to drive off the excess NH_3, then made slightly acidic (pH$\approx$5) with HCl and tungsten was precipitated with α-benzoin oxime. The decontamination from neighboring elements was very good, especially from Re. Chemical yields of 50–80% were obtained in separation times of $\approx$40 min. Sources of about 0.1–1.0 μCi of ^{190}W activity were routinely prepared in this manner.

The γ-ray spectra were obtained using a 50-cm^3 Ge(Li) detector which had a resolution of 1.0 keV at 122 keV and 1.9 keV at 1332 keV. The spectra were analyzed by means of the INTRAL[5] computer code, and the CLSQ[6] program was used for decay-curve resolutions. Energy and efficiency calibrations were determined with National Bureau of Standards and International Atomic Energy Agency γ-ray sources. Chemically separated tungsten sources were observed to have ^{190}Re ($T_{1/2}$ = 3.1 min)[7] in secular equilibrium with its parent ^{190}W. In addition to the ^{190}W-^{190}Re pair, radiations[8,9] from ^{189}W (11 min), ^{187}W (24 h), ^{185}W (75 day), ^{181}W (122 day), ^{179}W (38 min), ^{178}W (22 day), ^{177}W (2.2 h), and ^{176}W (2.5 h) were also observed. However, owing to differences in either their half-lives and/or their γ-ray spectra, these activities did not seriously interfere. The best sources of ^{190}W (containing the least amount of neutron-deficient W nuclides) were obtained from

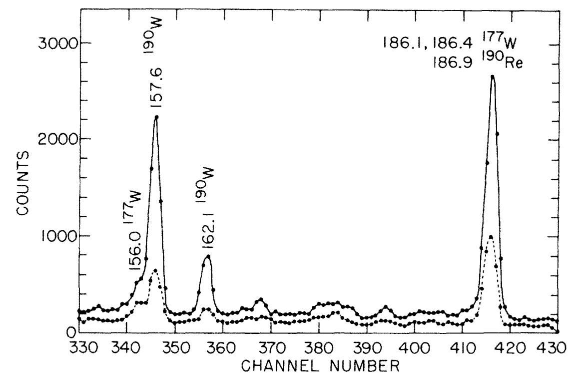

FIG. 1. γ-ray spectrum (150–200 keV) taken with a tungsten source containing ^{190}W. The solid line curve was accumulated approximately 50 min after the end of the irradiation. The dashed curve was accumulated approximately 150 min after the end of the irradiation.

the neutron irradiations.

In addition to the well-known[7,10] γ rays of 3.1-min ^{190}Re, the γ-ray spectra of the chemically separated tungsten sources were observed to have lines at 157.6 and 162.1 keV which decayed with the same 30.0-min half-life that the ^{190}Re lines followed. These two transitions were therefore assigned as primary radiations from the ^{190}W decay, and are shown in a portion of the γ-ray spectrum (Fig. 1). The line at 186.9 keV results from the ^{190}Re in equilibrium with the ^{190}W parent. Interferences from ^{177}W are also shown. In Table I are listed the γ-ray energies and intensities of the ^{190}W γ rays. All other γ rays were assigned to previously known nuclides of W and their daughter activities.

The γ-ray intensities of ^{190}W were normalized

TABLE I. γ-ray energies and intensities in the decay of ^{190}W.

		Transition intensity [a]			
E_γ [b]	I_γ [c]	$E1$	$M1$	$E2$	$M2$
157.6	39.1	46.1	96.1	56.0	387.5
		(0.118)	(1.457)	(0.431)	(8.910)
162.1	11.0	12.2	25.8	15.5	101.4
		(0.109)	(1.345)	(0.413)	(8.221)
Re K vacancies	77.0	(3.2)	(37.0)	(7.5)	(168.0)
		(0.9)	(9.9)	(2.0)	(43.9)

[a] The theoretical total conversion coefficients, given in parentheses under the calculated transition intensity, were taken from Ref. 11. The K vacancies for the various multipole orders are given in order of increasing energy, 157.6 keV (above) and 162.1 keV (below).

[b] The errors in the γ-ray energies are ±0.1 keV.

[c] The γ-ray intensities are normalized to 100 decays of ^{190}Re daughter (see text). The uncertainty in the intensity is ±10%.

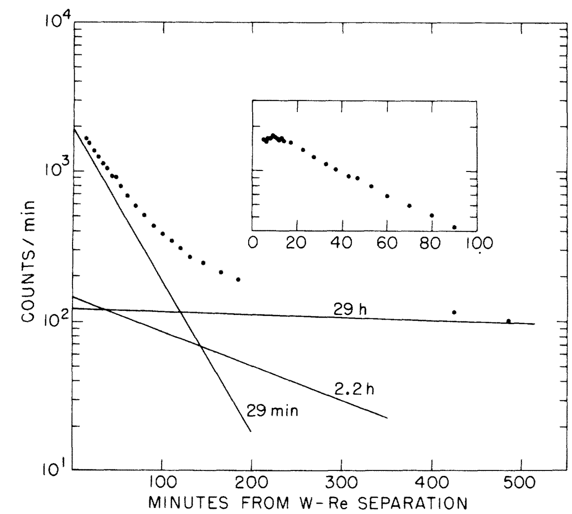

FIG. 2. Decay curve of the β-ray activity ($E_\beta > 900$ keV) from a tungsten source following separation of the ^{190}Re daughter activity from the ^{190}W parent. The inset shows the initial growth of activity resulting from the buildup of ^{190}Re (3.1 min).

to 100 decays of ^{190}Re (3.1 min) in secular equilibrium. The total ^{190}Re disintegration rate was determined by averaging the total intensity obtained from those γ rays whose individual intensities comprised more than 20% of the total decays. Uncertainty in the averaging was ±5%, and the overall uncertainty for intensities of the ^{190}W γ rays was ±10%.

The parent-daughter relationship between the 30.0-min tungsten activity and 3.1-min ^{190}Re was confirmed by a series of chemical "milking" experiments in which ^{190}Re was separated from the tungsten fraction at 10-min intervals and counted with Ge(Li) and plastic scintillation detectors. Milkings were performed in the following manner: the α-benzoin oxime precipitate of the W from the above procedure was destroyed with fuming nitric acid and W was adsorbed on an alumina column. Re was periodically eluted from the column with 0.9% NaCl aqueous solution (chemical yield of 80±10%), collected in glass vials, and counted. These fractions decayed with the appropriate 3.1-min half-life of ^{190}Re and exhibited all of the most prominent γ radiations. The initial activities of the Re fractions corrected to the time of separation from the tungsten, decreased with a half-life of 29±4 min and therefore the parent-daughter relationship between 3.1-min ^{190}Re and the 30-min tungsten activity is established.

Multiscaling of the β-ray activity above 900 keV from ^{190}W sources provided an additional verification of the genetic relationship between ^{190}W and its ^{190}Re daughter. This energy discrimination insured that the gross β activity would contain contributions from ^{190}Re but not ^{190}W. A decay curve from such a source is shown in Fig. 2. The initial rise in the activity is due to the growth of ^{190}Re following the Re-W chemical separation. Resolution of this decay curve yielded a 29 ± 2-min component due to the ^{190}W-^{190}Re chain, a 2.2-h component from the ^{177}W interference, and a longer-lived tail of 29 h due primarily to ^{187}W.

β-γ coincidence measurements were performed using the Ge(Li) detector to gate on the 157.6-keV γ ray and a plastic scintillator to detect the coincident β radiation. Energy calibration was performed using β-ray spectra from sources of ^{90}Sr, ^{137}Cs, ^{204}Tl, and ^{210}Bi. The coincidence measurement was repeated both on and off the γ-ray peak in order to evaluate the amount of interference from other radionuclides in the source. Accidental coincidences amounted to about 5–10% of the total coincidences and did not interfere with the β end-point measurement which gave a value of 0.95 ± 0.07 MeV. γ-γ coincidence measurements were not performed due to insufficient source strength.

III. DISCUSSION

The experimental data presented above are not sufficient to establish an unambiguous decay scheme for ^{190}W, although some general features can be deduced by making use of theoretical estimates of energy levels in ^{190}Re. The theoretical estimates are made with the use of the general systematics deduced from neighboring nuclei.[12,13]

The ground-state spin-parity of ^{190}Re has been assigned[10] $K^\pi = 2^-$ with a Nilsson configuration of $\frac{5}{2}^+[402]_p$, $\frac{9}{2}^-[505]_n$. In addition, the $I^\pi = 3^-$ ground-state rotational band member was observed[10] at 119 keV in the isomeric decay of ^{190}Re^m ($K^\pi = 6^-$, $\frac{5}{2}^+[402]_p$, $\frac{7}{2}^-[503]_n$). No other information is known about the level structure of ^{190}Re. The ground-state spin-parity of even-even ^{190}W is assumed to be 0^+. Its β-decay energy has been estimated[14] to be ≈1.2 MeV. The β decay should proceed via either allowed or first-forbidden transitions ($\Delta I = 0, 1$) to states in ^{190}Re which have $K = 0$ or 1.

Only two γ rays of 157.6 and 162.1 keV were observed in the decay of ^{190}W. Transition intensities calculated from the measured γ-ray intensities and theoretical[11] total interval conversion coefficients for assumed multipole orders of $E1$, $M1$, $E2$, and $M2$ are presented in Table I. Reference to Table I indicates that multipole orders of $M1$ and $M2$ for the 157.6- and 162.1-keV transitions, respectively, yield ≈ 100% of the ^{190}W transition strength. The transition strength was measured relative to the total ^{190}Re decay intensity. In addition, the total number of K vacancies produced was also measured and is listed in Table I. The two entries given for each multipole order of the 157.6- and 162.1-keV γ rays should add up to the measured value, and the two entries which meet that requirement are $M1$ and $M2$ for the 157.6- and 162.1-keV γ rays, respectively.

Theoretical calculations indicate that such a single cascade in ^{190}Re, involving two γ rays, should carry most of the transition intensity (≥90%) of the ^{190}W decay. In these calculations it is assumed that ^{190}Re is a strongly deformed nucleus with a deformation parameter of $\beta \approx 0.2$. We have followed the general procedure for calculating the splitting of the Gallagher-Moszkowski pairs ($K = |\Omega_p \pm \Omega_n|$) as given by Jones *et al.*[15] using a residual effective interaction for V_{np} given by a finite-range Gaussian central potential

$$V_{np} = \exp(-r^2/r_0^2)(V_{TE}P_{TE} + V_{TO}P_{TO} + V_{SE}P_{SE} + V_{SO}P_{SO}), \quad (1)$$

where P_{TE}, P_{TO}, P_{SE}, and P_{SO} are projection operators for the spin triplet (T) and singlet (S), even (E) or odd (O) relative orbital angular momentum. The computer program is one developed by Struble.[16] The strength parameters of the nuclear force used were $V_{TE} = -262$ MeV, $V_{SO} = 169$ MeV, $V_{TO} = -51$ MeV, $V_{SE} = 35$ MeV, and $r_0 = 1.5$ fm. These parameters were determined by a least-squares fit to the experimental[15,17-19] doublet splittings of ^{176}Lu, ^{182}Ta, ^{186}Re, and ^{188}Re. In Table II are given the estimated excitation energies of the various n-p configurations below 1 MeV in ^{190}Re. The $\frac{7}{2}^+[404]$, $\frac{3}{2}^+[402]$, and $\frac{1}{2}^+[411]$ proton orbitals were not included, as these states

TABLE II. Theoretical estimates of the excited levels of ^{190}Re below ≈1 MeV. The odd-odd configuration energies are given in keV, with the triplet configuration above and the singlet configuration below. The $K^\pi = 0^+$ state has been corrected for a calculated odd-even shift of −60 keV. These predicted levels are presented, in part, in Fig. 3.

	Proton	
Neutron	$\frac{5}{2}^+[402]_p$	$\frac{9}{2}^-[514]_p$
$\frac{9}{2}^-[505]$	2^-(0)	0^+(216)
	7^-(245)	9^+(491)
$\frac{7}{2}^-[503]$	6^-(173)	8^+(498)
	1^-(335)	1^+(568)
$\frac{3}{2}^-[512]$	1^-(280)	3^+(553)
	4^-(389)	6^+(713)
$\frac{1}{2}^-[510]$	3^-(375)	5^+(663)
	2^-(494)	4^+(805)
$\frac{11}{2}^+[615]$	8^+(473)	10^-(672)
	3^+(610)	1^-(791)

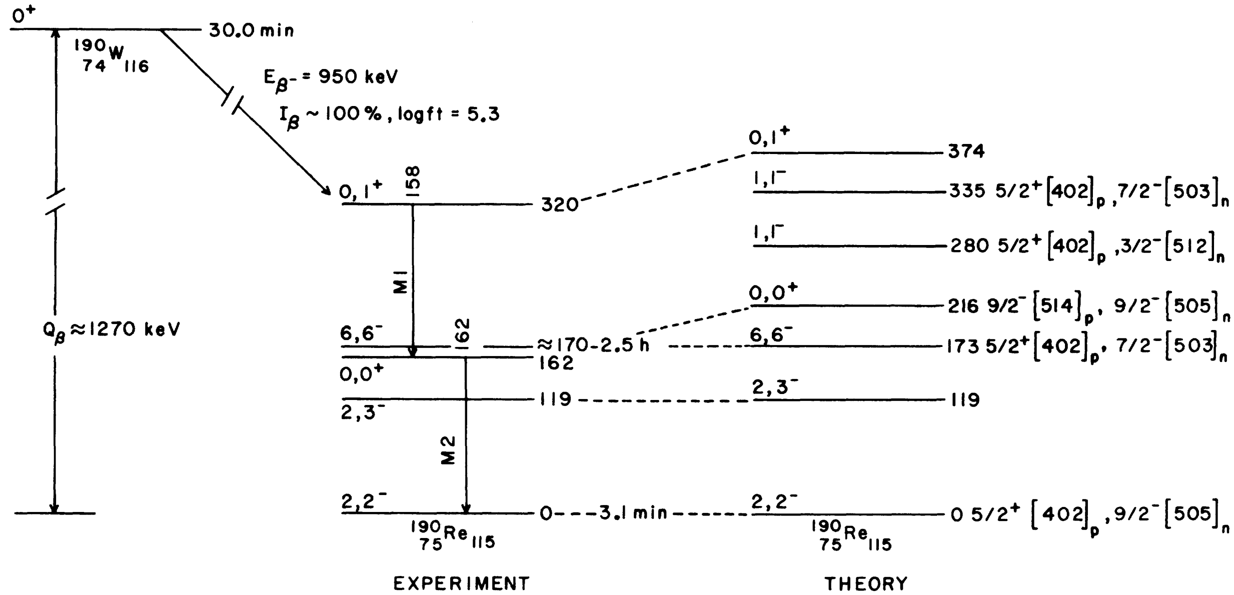

FIG. 3. Proposed decay scheme for ^{190}W. The theoretical level structure of ^{190}Re is predicted from results of the residual interaction calculation discussed in the text. (See also Table II.)

are not expected to play a major role in the decay of ^{190}W.

The β decay of ^{190}W should proceed largely to the low-lying $K^\pi = 0^+$, 1^+, and 1^- bands shown in Table II. β transitions to the low-lying $K^\pi = 1^-$ bands are expected to be very weak, since they are first-forbidden decays. Indeed, the $\frac{7}{2}^-[503]_n \to \frac{5}{2}^+[402]_p$ and $\frac{3}{2}^-[512]_n \to \frac{5}{2}^+[402]_p$ transitions are observed to exhibit logft values of 7.2 and 6.9, respectively, in the decay of ^{188}W.[19] The β decay to the $K^\pi = 1^+$ band in ^{190}Re is expected to have a logft value similar to that inferred[20] from the decay of ^{182}Hf^m. The logft value observed in Ref. 20 for this decay is ≥ 7.1, which, after the appropriate pairing corrections gives a single-particle logft of ≥ 5.4. Application of the pairing factors for the ^{190}W decay to this single-particle value yields an expected logft in the present case of ≥ 6.9. Of course, the β decay to the $K^\pi = 1^+$ state is also hindered by the decreased transition energy.

On the other hand, we anticipate that the β decay to the $K^\pi = 0^+$ band, whose configuration is $(\frac{9}{2}^-[514]_p, \frac{9}{2}^-[505]_n)$, will have a log$ft$ of approximately 5.4. This predicted value is based upon the observation[7] of an ≈ 1.8-MeV β group in the 9.7-min decay of ^{191}Re to the $(\frac{9}{2}^-)$ ground state of ^{191}Os, which exhibits a single-particle logft value of 5.2. No other allowed $n \to p$ transitions terminating in a $\frac{9}{2}^-$ odd-neutron state of ^{191}Os are possible in this mass region except $\frac{9}{2}^-[505]_n \to \frac{9}{2}^-[514]_p$. Thus the $\frac{9}{2}^-[514]_p$ and $\frac{9}{2}^-[505]_n$ ground-state assignments are implied by these data for ^{191}Re and ^{191}Os, respectively, and the low logft value is attributed to the allowed character of this $n \to p$ transition. Application of the ^{190}W $\to$ ^{190}Re pairing factors to this single-particle logft value yields the predicted value of 5.4. Thus, the β decay of ^{190}W is expected to be dominated by the transition to the $K^\pi = 0^+$ band in ^{190}Re.

The $0^+ \to 0^+$ β transition between ^{190}W and ^{190}Re is, however, greatly hindered because essentially all of the Fermi strength is concentrated in the energy-forbidden transition to the isobaric analog state. Indeed, the $0^+ \to 0^+$ transition in the decay of ^{188}W to ^{188}Re is observed[19] to have a logft value of 9.9. On the other hand, the $0^+ \to 1^+$ Gamow-Teller β transition to the same band does not suffer from this severe isospin hindrance and can therefore be expected to proceed in a manner characteristic of the allowed $\frac{9}{2}^-[505]_n \to \frac{9}{2}^-[514]_p$ transition. Such a transition is not observed in the ^{188}W decay because the 1^+ state lies too high in energy. The $K^\pi = 0^+$ band is known[19] to have an odd-even shift of -54 keV in ^{188}Re, where the calculated value[19] is -60.1 keV. Using this same calculated value for the odd-even shift in ^{190}Re, one would predict the 1^+-0^+ energy difference to be $\Delta E = 2(\hbar^2/2\mathcal{I}) + 2 \times 60.1$ keV, where $\hbar^2/2\mathcal{I} = 20$ keV, yielding $\Delta E \approx 160$ keV. We therefore propose that the 157.6-keV γ ray represents the $1^+ \to 0^+$ $M1$ transition in ^{190}Re, fed by the allowed Gamow-Teller β decay of ^{190}W. The $K^\pi = 0^+$ bandhead then decays by $M2$ radiation (162.1 keV) to the 2^- ground state of ^{190}Re.

The $0^+ \to 2^-$ ($M2$) transition should have a measurable lifetime. A lifetime of ≈90 μsec was estimated by comparison with the $\frac{9}{2}^-[514]_p \to \frac{5}{2}^+[402]_p$ ($M2$) transition in ^{187}Re. No attempt was made to measure this lifetime.

In Fig. 3 is shown the proposed decay scheme of ^{190}W, including the known excited states of ^{190}Re. For comparison, the theoretical predictions are also shown. The prediction of $Q_\beta = 1.21$ MeV by Viola, Swant, and Graber[14] is in excellent agreement with the deduced value of 1.27 ± 0.07 MeV. $Q_\beta = 0.96$ MeV predicted by Garvey *et al.*[21] is somewhat lower.

IV. ACKNOWLEDGMENTS

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