α and β decays of $^{169-173}$Os and the nuclear structure of the daughter isotopes

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The α and β decays of $^{169-173}$Os were studied using ^{114}Cd(^{58}Ni,xn) and ^{140}Ce(^{36}Ar,xn) reactions. For ^{169,171}Os new α rays and α-coincident γ rays were observed; for $^{170-173}$Os β-delayed γ transitions could be identified for the first time. Evidence for isomeric states in ^{171,173}Re was found. The nuclear structure in the daughter isotopes is interpreted in terms of single-particle states in the frame of the Nilsson model.

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I. INTRODUCTION

The region above the $N = 82$ and below the $Z = 82$ shell closures in the chart of nuclides reveals interesting features. Here the transition from the dominant α-decay mode of the very neutron-deficient nuclei to β^+ and/or EC decay of nuclei closer to stability can be studied. The ground-state shapes vary from highly deformed to nearly spherical nuclei. Prolate deformed $h_{9/2}\,\frac{1}{2}^-[541]$ proton intruder states have been observed, which, for example, in combination with the $\frac{9}{2}^-[514]$ Nilsson state near the Fermi level give rise to the existence of isomerism in ^{167,169}Re [1]. Isomerism was also proposed for ^{171}Re on the basis of a comparison of its β decay [2] and the ^{175}Ir α decay [3].

Information on these nuclei can be obtained by in-beam γ spectroscopy and by α and β decay measurements. The first method gives results on the rotational bands, but often fails to connect the low-spin low-energy bandheads. Such states can be fed by β or α decay of the low-spin ground and/or isomeric states of the respective parent nuclei, and transitions between them are accessible through γ spectroscopy of these decays. However, because of the high refractoriness of elements in this region, ion-source online (ISOL) methods are difficult to apply. In these cases, a He jet combined with a fast tape-transport system is a good tool for decay studies.

The experiments reported in this paper complete a series of systematic decay investigations of neutron-deficient ^{164,165}Hf, $^{160-164,168}$Ta [4,5], $^{162-174}$W [5–10], $^{166-171}$Re [2,11], $^{171-177,179,180}$Ir [3,12,13], and $^{177-181}$Pt [1]. Here we report on the investigations on $^{169-173}$Os, filling the gap between rhenium and iridium isotopes.

II. EXPERIMENTAL PROCEDURE

The experiments were performed at the VICKSI accelerator of the Hahn-Meitner-Institut, Berlin. Our apparatus consisted of a NaCl He jet and a fast tape-transport system, the setup being similar to that of our previous experiments.

The incoming heavy-ion beam was reduced in energy by the 5 mg/cm^2 Ta entrance window of the target chamber and by additional optional degrader foils in front of the target. The reaction products were stopped in the helium gas and swept out along with the NaCl-He aerosols through a 1.2 mm diameter Teflon capillary to a shielded measuring site, about 10 m away from the target chamber. They were sprayed onto a tape and periodically moved into measuring position. The cycle time was chosen according to the half-lives of the nuclei under investigation. We used a detector arrangement of two high-resolution germanium detectors (one low-energy and one high-energy 70% detector) in close 180° geometry with a 450 mm^2 silicon surface-barrier α detector in between. The detectors were set up with standard fast-slow coincidence circuits. List mode and singles spectra were recorded. For half-life analysis the latter were divided into eight successive subgroups. The calibration of the detectors was performed with standard sources. The experimental parameters are compiled in Table I.

The isotopes under investigation were produced by compound-nucleus reactions followed by the evaporation of neutrons. Since the evaporation of protons and α particles is also likely in these compound-nucleus reactions and due to the occurrence of multinucleon transfer reactions between beam and tantalum degrader or cerium target foils various methods for an assignment of the observed radiation to the respective isotopes were applied. In fact, the intensity of the radiation of projectilelike ^{42}Sc^m, ^{46}Sc^m, ^{49}Cr, ^{50}Mn^m, ^{52}Fe and targetlike ^{135}Ce^m, ^{138}Xe, ^{179}Os, ^{180}Re, ^{181}Os reaction products was comparable to that of $^{170-173}$Os from the compound-nucleus reactions.

In many cases the mass number can be determined by the measurement of excitation functions and a comparison with known neighbors. The element assignment of new radiation can be obtained by the measurement of coincident x rays from converted transitions and/or

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TABLE I. Survey of the experimental parameters.

Name of	Beam				Target		Cycle	Counting	Investigated
experiment	isotope	energy[a]	charge	current[b]	thickness	isotope	time	time	isotope(s)
os1	^{58}Ni	267 MeV	12^+	47.6 nA	3.44 mg/cm^2	^{114}Cd[c]	8 s	33.5 h	^{168,169}Os
os2	^{36}Ar	210 MeV	9^+	35.1 nA	1.8 mg/cm^2	^{140}CeF$_3$[d]	16 s	15.4 h	^{170}Os
os3		203 MeV		47.7 nA				13.6 h	^{171}Os
os4		194 MeV		54.5 nA				12.4 h	^{171,172}Os
os5		185 MeV		55.5 nA				3.7 h	^{172,173}Os
os6		178 MeV		57.2 nA				2.6 h	^{173}Os
os7	^{36}Ar	178 MeV	9^+	44.2 nA	1.8 mg/cm^2	^{140}CeF$_3$[d]	48 s	7.8 h	^{172,173}Os

[a]In front of the target.
[b]Average during experiment.
[c]Purity 99.9%.
[d]Target composition: 99.3% ^{140}Ce, 0.7% ^{142}Ce.

emitted after electron capture decays. Coincidence relations to radiation which has already been attributed are also helpful. Another criterion is the half-life, which is of particular relevance in cases where none of the methods mentioned above can be applied. A last tool which was applied is the cross bombardment, i.e., the comparison of the spectra with those obtained from reactions with a compound system having one proton less. For example, we will refer to the rhenium data of Refs. [11,14] measured earlier.

III. SPECTROSCOPIC RESULTS

Here we report on the decays of the isotopes $^{169-173}$Os. In addition to the already known α rays, α fine structure and $\alpha\gamma$ coincidences were observed in the decays of ^{169,171}Os. For the first time, β-delayed γ rays of $^{170-173}$Os were identified. Decay schemes could be derived from the $\gamma\gamma$ and γX coincidences

A. Decay of ^{168}Os and ^{169}Os

The experimental parameters for the os1 measurement are given in Table I. The range of the beam energy in the target corresponded to the optimized production of ^{168,169}Os [15,16].

In the α spectrum (Fig. 1), a peak with an energy of 5.674 (8) MeV and a half-life of 2.1 (6) s was observed, which values correspond to the reported radiation of ^{168}Os: 5.660 (10) MeV [17,18], 5.670 (10) MeV [19], 5.680 (3) MeV [20], and 5.662 (8) MeV [21] with the half-lives 1.9 (1) and 2.0 (4) s [17], 2.4 (2) s [18], 2.2 (1) s [19], and 2.0 (2) s [21].

During one-and-a-half days of measurement no Re-K-x-ray coincident γ rays were observed, and no candidates for β-delayed γ radiation of the ^{168}Os decay were seen in the singles and the multiple spectra, which is in accordance with the α-branching ratio of 49(3)% reported in Ref. [19].

For ^{169}Os, only α decay has been reported so far [17–22], with an α energy of 5.56 MeV and a half-life of approximately 3 s. These data are summarized in Table II. In addition, a second α line with an energy in the range of 5.47–5.54 MeV and with an intensity of about one-third of the 5.56 MeV line was measured [17,21]. Since the half-lives of both lines were reported to be nearly identical, the two lines were interpreted as α fine structure components. In an experiment performed by Enge *et al.* [19] a weaker 5.521 MeV line with a smaller half-life was observed besides the strong 5.573 MeV line. Due to the fact that the intensity ratio of both lines varied with the projectile energy, the authors tentatively claimed an isomeric state in ^{169}Os.

Our α spectrum (os1) is displayed in Fig. 1. In addition to the well-established α lines, two smaller peaks with energies of 5.508 and 5.536 MeV and half-lives of 6 (3) and 3.4 (8) s show up. The latter are in agreement

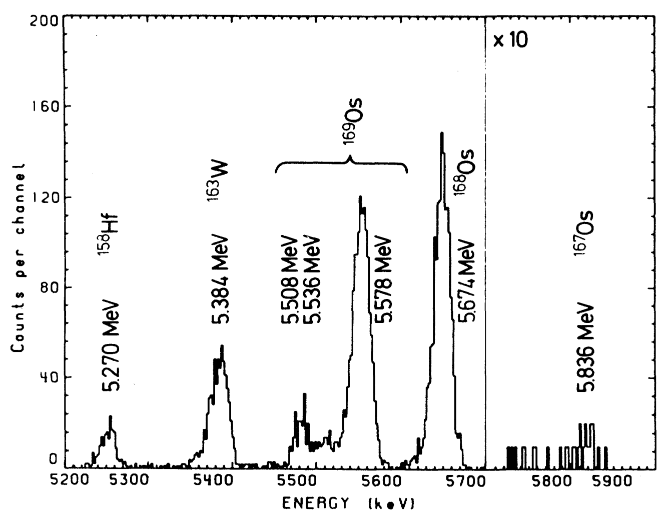

FIG. 1. Alpha spectrum of osmium isotopes observed in the reaction ^{58}Ni+^{114}Cd. The beam energy in the target was 212–267 MeV, the cycle time was 8 s, and the total measurement time was 33 h.

TABLE II. Energies E_α, relative intensities I_α^{rel}, half-lives $T_{1/2}$, and coincident γ radiation of α rays from the decay of ^{169}Os.

Ref.	E_α [MeV]	I_{rel} [%]	$T_{1/2}$ [s]	Coinc. γ rays [keV]
[22]	5.56 (2)		3.0 (5)	
[18]	5.57 (1)		3.2 (2)	
[17]	5.56 (2)	75		
	5.47−5.54	25		
[19]	5.572(10)		3.4 (2)	
	5.521(10)		2.7 (3)	
[20]	5.582 (4)			
[21]	5.564 (8)	80	3.5 (2)	
	5.47−5.54	20	3.5 (2)	
This work	5.578 (8)	80	3.2 (3)	
	5.536 (10)	8	3.4 (8)	43
	5.508 (8)	12	6 (3)	W K x ray, (28),(43),72

with the half-life of 3.2 (3) s of the 5.578 MeV peak. In addition to the α lines mentioned above [17–19], a 5.500 MeV α line with a half-life of 2.0–2.5 s was attributed to the decay of ^{165}Re [23] or ^{166}Re [11,18,20,21]. However, according to our cross-section calculations [15] and to the inspection of our α and β spectra, the isotopes ^{165,166}Re and their short-lived β precursors ^{165,166}Os were unlikely to be produced in the experiment OS1.

The α fine structure character of the 5.508 and 5.536 MeV α rays was reinforced by the following results (cf. Table II).

(a) In the γ spectrum gated by 5.578 MeV α rays only chance coincidences were observed. This fact confirms the interpretation that this α line is a ground-state to ground-state transition.

(b) In coincidence with 5.536 MeV α rays, we observed 43 keV γ rays. The measured γ intensity is in agreement with α fine structure decay if we adopt an $M1$ multipolarity [24] for the 43 keV transition. Other multipolarities can be excluded. Neither K x rays nor L x rays from L conversion were seen. The latter were below the detection threshold of our coincidence γ-ray spectrum.

(c) In coincidence with 5.508 MeV α rays, we observed W-K–x-ray radiation. The nonobservance of 70 keV γ rays and our experimental x-ray intensity imply that the adopted 70 keV transition has $M1$ character [24]. A weak indication for 43 and 28 keV γ rays was observed in this coincidence spectrum.

The α-decay scheme derived from these data is shown in Fig. 2.

B. Decay of $^{170-173}$Os

The isotopes $^{170-173}$Os were produced in the reaction ^{140}Ce(^{36}Ar,xn) in the experiments OS2–OS6 (cf. Table I). The beam energy was varied from 178 to 210 MeV. Excitation functions were taken with a cycle time of 16 s. One experiment (OS7) was performed with a cycle time of 48 s to optimize the production of the longer-lived isotopes ^{172}Os and ^{173}Os. As in the case of the lighter isotopes, only the α decays of $^{170-173}$Os have been identified so far. Some γ rays with half-lives $\leq$30 s which were observed after proton spallation of mercury had been tentatively assigned to the decays of ^{172}Os or ^{173}Os [25].

The α decay of ^{170}Os with an α energy of 5.40 MeV and a half-life of about 7 s is well established [18–21,26]. The present results of the OS2 and OS3 experiments are 5.403 (7) MeV and 7.9 (3) s, in good agreement with the values in the literature. In the γ spectra, we observe two new γ rays of 216 and 162 keV which are coincident with Re-K–x-ray radiation and whose intensities vary with the beam energy in the same way as that of the 5.403 MeV α line. The half-lives of the new 216 and 162 keV γ rays are 8.5 (5) and 9.3 (16) s and agree with the α half-life. Hence, we attributed these γ rays to the decay of ^{170}Os. The γ data are compiled in Table III. Since the two γ rays are not coincident with one another, we adopted levels at 162 and 216 keV in the ^{170}Re daughter nucleus. Neglecting the internal conversion of the 216 and 162 keV γ rays, we deduced an α branching b_α =9(2)%, taking into account the $M1$ conversion of these transitions [24], b_α =5(1)%. This can be compared to the value of 12(1)% reported previously [19] and to the estimated value of about 3% [18].

The α decay of ^{171}Os with E_α = 5.24 MeV and $T_{1/2}$ = 8 s has been known for a long time [18,26,27]. In addition to this α peak we observed a weaker line at an energy of 5.166 MeV with a comparable excitation function and the same half-life (see Table IV). Thus, α fine structure in the ^{171}Os decay is indicated and confirmed by the measurement of the α-coincident γ spectrum (cf. Fig. 3).

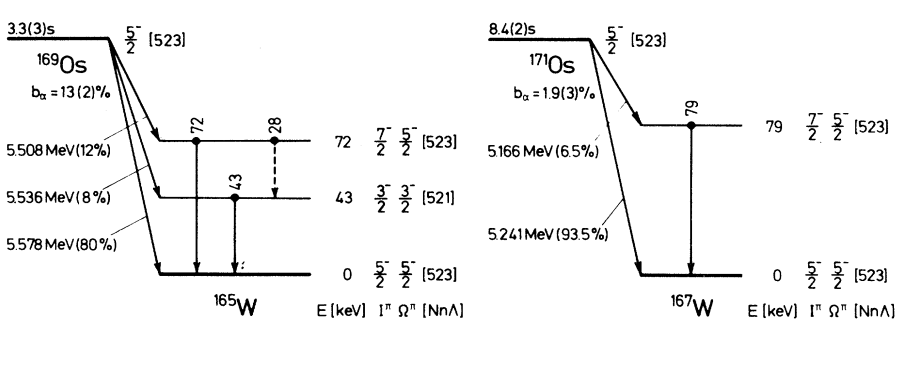

FIG. 2. Alpha-decay schemes of ^{169,171}Os. The α-branching ratio of ^{169}Os was taken from the 5.573 MeV α-branching ratio of Ref. [19] and scaled with our experimental relative α intensities. The β-decay branch of ^{171}Os is shown in Fig. 4.

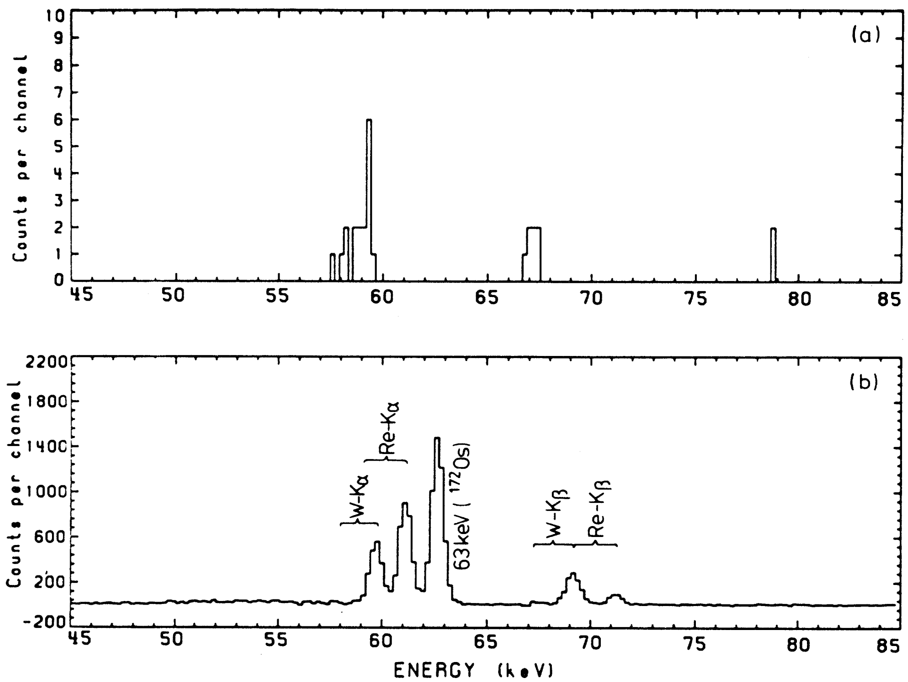

FIG. 3. (a) X and γ rays in coincidence with 5.166 MeV α rays in ^{171}Os decay measured in 48 h [sum of spectra os2–os6 (cf. Table I)]. (b) Total projection of γ ray coincidences measured in 4 h, experiment os4.

TABLE III. Energies E_γ, relative intensities I_γ^{rel}, half-lives $T_{1/2}$, and measured coincidences of γ rays following the β decays of $^{170-173}$Os.

Isotope	E_γ [keV]		I_γ^{rel} [%]		$T_{1/2}$ [s]		Coinc. γ rays
^{170}Os	161.8	(4)	35	(3)	9.3	(16)	Re K x ray, 511
	216.3	(4)	100		8.5	(5)	Re K x ray, 511
^{171}Os	189.8	(4)	100		10.0	(10)	(Re K x ray), (511)
	326	(1)	11	(3)			Re K x ray
	705.0	(5)	17	(3)	8.0	(24)	Re K x ray, 511
^{172}Os	63.0	(3)	100[a]		22.[a]	(2)	Re K x ray, 91[b], 98, 107, 121, 122, 177, 211, 226, 228, 511, 843
	98.4	(4)	≈ 1				Re K x ray, 63, 511
	106.8	(4)	≈ 1				Re K x ray, 63, 511
	120.7	(4)	≈ 2				Re K x ray, 63, 177, 511
	122.0	(4)	≈ 1				Re K x ray, 63, 511
	159.9	(4)	4	(1)	25	(5)	Re K x ray, 511
	176.7	(2)	40	(6)	18.4	(10)	Re K x ray, 63, 122, 511
	187.0[c]		<2.5				
	211.1	(4)	≈ 2		18	(5)	Re K x ray, 63, 511
	226.1	(5)	≈ 2				Re K x ray, 63, 511
	228.4	(4)	≈ 2				Re K x ray, 63, 511
	239.8	(2)	37	(7)	19.1	(13)	Re K x ray, 511
	276.0[c]		<1.5				
	285.0[c]		<1.5				
	291.5	(3)	5.5	(1.2)			Re K x ray, 511
	843.3	(10)	4	(2)			Re K x ray, 63, 511
	1120.1	(15)	15	(10)			Re K x ray, 511
^{173}Os	141.6	(3)	15	(6)	28	(4)	Re K x ray, 157, 511
	157.2	(4)	4	(2)			Re K x ray, 142, 511
	187.0[c]		<2				
	214.7	(3)	100		22	(1)	(Re K x ray), (511)
	276.0[c]		<1				
	285.0[c]		<1				
	299.3	(5)	20	(5)	23	(3)	Re K x ray, 511

[a]Corrected for contribution of the decay of ^{49}Cr [35].
[b]From the decay of ^{49}Cr [35].
[c]These γ rays of Ref. [25] were not observed in our experiment.

TABLE IV. Energies E_α, relative intensities $I_\alpha^{\rm rel}$, half-lives $T_{1/2}$, and coincident γ radiation of α rays from the decay of ^{171}Os.

Ref.	E_α [MeV]	$I_\alpha^{\rm rel}$ [%]	$T_{1/2}$ [s]	Coinc. γ rays [keV]
[26]	5.24 (1)		8.2 (8)	
[18]	5.24 (1)		7.8 (10)	
[27]	5.267 (15)			
This work	5.166 (10)	6.5	8 (2)	W K x ray, 79
	5.241 (7)	93.5	8.3 (2)	

Therefore a K-conversion coefficient α_K of ≈ 10 can be estimated for the 79 keV γ ray, which is in agreement with the calculated value of 8.4 for an $M1$ transition [24]. The α-decay scheme of ^{171}Os is also shown in Fig. 2.

The measurement of excitation functions for new γ rays of 190 and 705 keV, their half-lives (cf. Table III), and the coincidence of the less intense 705 keV γ transition with Re K x rays resulted in their assignment to the decay of ^{171}Os. The observed but in comparison less frequent 190 keV Re-K–x-ray coincidences could be explained by a lifetime of the 190 keV level (see below). A weaker 326 keV transition was tentatively assigned to the ^{171}Os decay, too. A survey of the β-delayed γ radiation of ^{171}Os is given in Table III. The derived decay scheme is shown in Fig. 4. Assuming an $E2$ multipolarity for the 190 keV γ transition (cf. Sec. IV A 1) we derived an α-branching ratio of 1.9(3)%, which is in agreement with the value 1.7(3)% of Ref. [27].

The production of ^{172}Os was optimized in experiment OS7 (cf. Table I). The previously known α-decay data of E_α =5.105 (10) MeV and $T_{1/2}$ =19 (2) s [28] were confirmed by our present results E_α = 5.100 (7) MeV and $T_{1/2}$ = 20 (2) s.

Because of the similar half-lives of ^{172}Os and ^{173}Os, the measurement of excitation functions is indispensable for the γ ray identification. Due to these excitation functions and to coincidences with Re K x rays we attributed the strong γ transitions of 63, 177, and 240 keV to the decay of ^{172}Os. The assignment of weaker γ rays, namely, of 98, 107, 121, 122, 211, 226, 228, and 843 keV, is suggested by their coincidence relations (cf. Table III) and/or excitation functions. A decay scheme is given in Fig. 5. The 240 and 292 keV transitions are included as crossover transitions. The 1120 keV and the 160 keV γ rays, which are not included, might represent ground-state transitions.

In order to derive the total conversion coefficient $\alpha_{\rm tot}$ of the 63 keV transition, the number of measured 63–177 keV coincidence events was compared with the number of observed 177 keV quanta measured simultaneously in the singles spectra. This comparison yielded $\alpha_{\rm tot}$(63 keV)=0.4(1), pinning down an $E1$ multipolarity ($\alpha_{\rm tot}^{\rm theor}$ = 0.25 [24]).

In a spallation experiment Berlovich *et al.* [25] observed four γ lines of 177, 187, 276, and 285 keV (with relative intensities of 100%, 50%, 25%, and 30%) in a chemically separated sample, which exhibited half-lives of less than 30 s and therefore were attributed to the decays of ^{172}Os or ^{173}Os. We have observed the 177 keV radiation (see above) and ascribed it to the ^{172}Os decay. However, the remaining γ rays were not present in our experiments OS4–OS7. Upper limits of their intensities are given in Table III. Assuming the total β strength of the ^{172}Os decay to be represented by the 63, 160, 240, 292, and 1120 keV transitions (cf. Fig. 5) and taking into

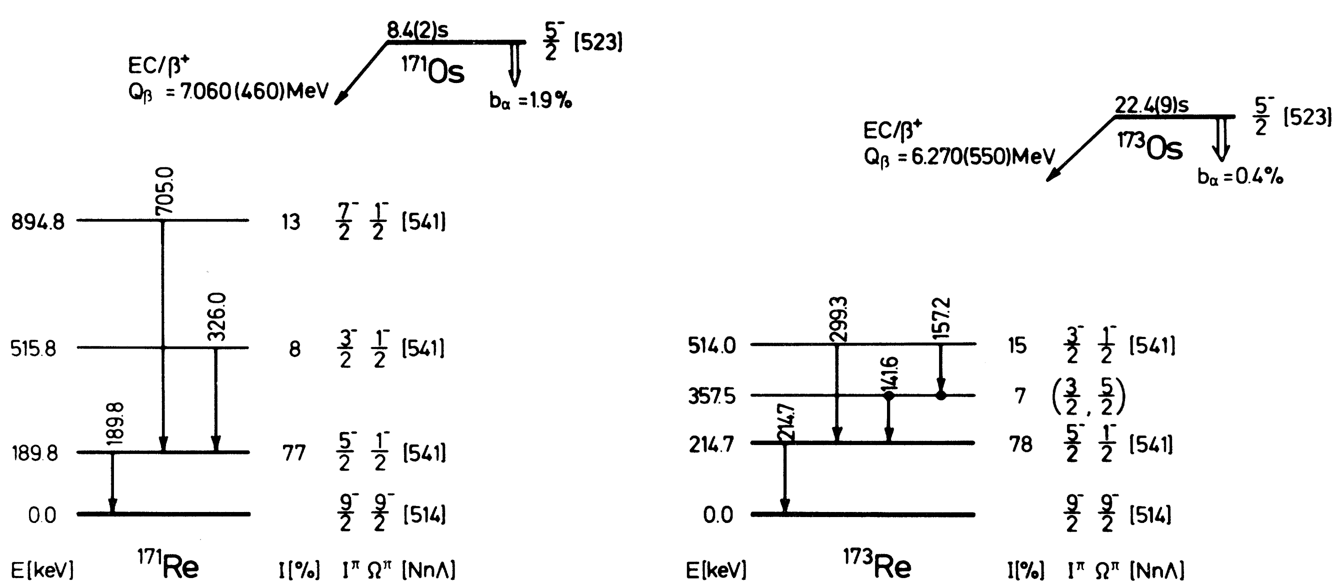

FIG. 4. Beta decay schemes of ^{171,173}Os. The systematic Q values are taken from Ref. [44]. The α-decay branch of ^{171}Os is shown in Fig. 2.

account the measured total conversion coefficient of the 63 keV radiation, we have calculated the α-branching ratio b_α =1.1(2)%, which is larger than the previous value of less than 0.3% [28].

As for ^{172}Os, the most prolific data for ^{173}Os originate from the experiment OS7. We measured the α decay of ^{173}Os with an α energy of 4.938 (7) MeV and a half-life of 22 (4) s. These results are in agreement with the previous values of 4.94 (1) MeV and 16 (5) s reported by Borggreen and Hyde [28]. Two Re-K-x-ray coincident γ lines of 142 and 299 keV with similar half-lives as the α decay show excitation functions which are similar to those of known γ rays from ^{173}Re decay [14,29] and to the 4.938 MeV α line of ^{173}Os. Hence, they are assigned to the decay of ^{173}Os. In addition, a weaker 157 keV γ transition was measured corresponding in energy to the difference in the γ-ray energies given above. These results are compiled in Table III.

A very strong 214.7 keV transition displays an excitation function typical of A = 173. Its measured half-life is 22 (1) s. However, the number of coincident Re K x rays is compatible with zero. Although its attribution to the same decay of ^{173}Os is suggested by the half-life, the 214.7 keV γ ray might be interpreted as an isomeric transition in ^{173}Os or as β-delayed radiation in the decay of ^{173}Re. However, the nuclear structure of ^{173}Os has been carefully investigated in in-beam [30] and decay spectroscopic work [3]. No 215 keV γ rays were reported, and

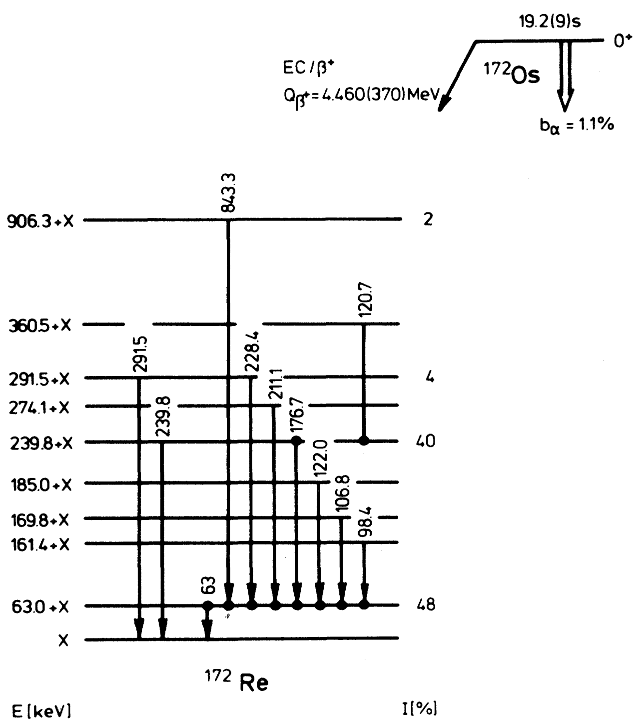

FIG. 5. (Partial) β decay scheme of ^{172}Os. Beta intensities of the order of 1% are not noted. The systematic Q value is taken from Ref. [44].

there seems to be no reasonable opportunity to place an isomeric level in ^{173}Os which is depopulated by such a transition. A similar argument concerns the situation in ^{173}W, which has been investigated by in-beam [31] and ^{173}Re decay [14,29] spectroscopic studies. Hence we conclude that the 215 keV γ ray originates from the ground-state ^{173}Os β decay. Due to the high γ intensity, we expect a level in ^{173}Re at this very energy which is fed via weaker γ transitions and directly via β decay. As its lifetime is considerably larger than the time-to-amplitude converter (TAC) range of 1 μs (and considerably smaller than the cycle time), the failure to observe coincident γ-, K–x-ray, or annihilation radiation is easily explained. In Sec. IV A 1 such an interpretation will be confirmed by the discussion of the nuclear structure in these deformed nuclei.

A decay scheme of ^{173}Os is given in Fig. 4. As discussed below, we may adopt the $E2$ multipolarity for the 215 keV transition and derive an α-branching ratio of ^{173}Os $b_\alpha = 0.4(2)\%$. Again this value is higher than the result $b_\alpha = 0.021(^{+13}_{-6})\%$ of Ref. [28].

IV. DISCUSSION

A. Nuclear structure in the rhenium daughter isotopes

Prolate deformed nuclei are reached in the β decays of $^{170-173}$Os with deformation parameters of $0.20 < \beta_2 < 0.26$ (corresponding to $0.18 < \epsilon < 0.24$) [32]. In this region the 75th proton may occupy the intruder level $h_{9/2}\,\frac{1}{2}^-[541]$ as well as $h_{11/2}\,\frac{9}{2}^-[514]$, $d_{5/2}\,\frac{5}{2}^+[402]$, or $g_{7/2}\,\frac{7}{2}^+[404]$. The first two were used to describe the discovery of isomerism in ^{167}Re and ^{169}Re [11].

1. *Odd isotopes ^{171,173}Re*

In-beam studies of ^{173}Re have revealed rotational bands built on the $\frac{9}{2}^-[514]$ and $\frac{5}{2}^+[402]$ bandheads as well as stretched $E2$ transitions in the decoupled $\frac{1}{2}^-[541]$ band leading to the $\frac{5}{2}^-$ member which is 118 keV below the $\frac{5}{2}^+[402]$ state [33,34]. The ground state of ^{173}Os has the $\frac{5}{2}^-[523]$ characterization, which was derived from in-beam measurements [30] and is in accordance with ^{173}Ir β-decay investigations [3].

We tentatively assume an allowed β decay leading to the $\frac{5}{2}^-\,\frac{1}{2}^-[541]$ state in ^{173}Re, which could be deexcited by the intense 215 keV γ ray in ^{173}Os β decay. A 215 keV transition to the $\frac{9}{2}^-$ ground state would exhibit a lifetime in the order of microseconds [35]. This fact could account for the missing coincidences for this line.

The γ rays of 142 and 299 keV are assumed to deexcite levels fed in an allowed β decay of ^{173}Os, which decay to the 215 keV state. With the decoupling parameter of ≈5.1 derived from the data of Ref. [33], one of these levels can be identified as a lower-spin band member of the decoupled band built upon the $\frac{5}{2}^-\,\frac{1}{2}^-[541]$ level (cf. Fig. 4). Such an interpretation fits well into the systematics of experimental single-particle level energies for the 75th proton compiled in Fig. 10 of Ref. [11].

In ^{171}Re the situation is similar. In-beam studies show the $\frac{5}{2}^+[402]$ state to lie 42 keV above the $\frac{5}{2}^-\frac{1}{2}^-[541]$ state, whose excitation energy is less than 200 keV above the $\frac{9}{2}^-[514]$ ground state [36,37]. As in the case of ^{173}Re we assume an allowed β decay of the $\frac{5}{2}^-[523]$ ^{171}Os ground state [30] to the $\frac{5}{2}^-\frac{1}{2}^-[541]$ state in ^{171}Re, which is deexcited by the strong 190 keV radiation. Again, due to a μs lifetime, coincidences with this line are suppressed. This is in agreement with the observation of a favored α decay of the $\frac{5}{2}^-\frac{1}{2}^-[541]$ ^{175}Ir ground state to the same excited state in ^{171}Re, where no $\alpha\gamma$ coincidences could be measured either [3].

According to the decoupling parameter derived from the level energies of the $\frac{1}{2}^-[541]$ band in ^{171}Re [36], we identify the 895 keV level with the $\frac{7}{2}$ member of this band, and the 326 keV transition observed in our spectra might connect the $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states, as shown in Fig. 4. However, an interpretation of the higher-lying 895 keV level as the $\frac{3}{2}^+[402]$, $\frac{5}{2}^+[402]$, $\frac{7}{2}^+[404]$, or even as the $\frac{7}{2}^+[523]$ state cannot be completely excluded.

2. *Even isotopes* ^{170,172}*Re*

For the even isotopes ^{170,172}Re the coupling of proton and neutron quasiparticle configurations has to be considered. For the discussion, the $\frac{9}{2}^-[514]$, $\frac{1}{2}^-[541]$, and $\frac{5}{2}^+[402]$ proton states are adopted. The possible neutron states are $\frac{5}{2}^-[523]$, $\frac{5}{2}^+[642]$, $\frac{3}{2}^+[651]$, $\frac{1}{2}^-[530]$, $\frac{1}{2}^+[660]$, $\frac{7}{2}^+[633]$, and $\frac{3}{2}^-[521]$. However, only the low-spin states can be reached in the β decay of the parent isotopes ^{170,172}Os with spin 0^+. The spin coupling rules [38] mainly suggest 1^+, 2^+, and 5^+ states.

In the β decay of ^{170}Re, the feeding of excited $2^+, 4^+$ [39] and $4^+, 6^+$ states [40] in ^{170}W was observed. In a recent publication, a complex decay scheme with a ground-state spin (5) of ^{170}Re was constructed [11]. A direct feeding of the two levels at 162 and 216 keV in the (allowed) β decay of ^{170}Re might rather suggest the low-spin assignments of ^{170}Re states, resulting in a 1^+ characterization of the 162 and 216 keV levels. However, since we cannot exclude the presence of unobserved higher-lying γ transitions, no spin assignments were derived in this measurement. It should be added that the presence of two states with distinct half-lives in ^{170}Re might explain the different (2^+) [39] and (5^+) [40,11] attributions according to the β feeding of excited states in ^{170}W, because the relative production of these states depends on the different experimental parameters.

In the β decay of ^{172}Re, Berlovich *et al.* identified two components decaying with a 55 (5) s half-life arising from a state with spin (2) and with 15 (3) s from a state with spin (5) [39,41]. In our decay scheme of ^{172}Os (Fig. 5), we placed two levels at 63 and 240 keV in ^{172}Re which are strongly fed in the β decay of ^{172}Os. Due to the measured multipolarity of the 63 keV transition, we propose the 2^+ spin assignment of the lowest state shown in Fig. 5.

B. Fine structure in the α decays of ^{169,171}Os

In the α decays of ^{169,171}Os we have observed fine-structure components which are coincident with γ transitions in the daughter nuclei ^{165,167}W (Fig. 2). The ground-state of ^{171}Os was identified as a $\frac{5}{2}^-[523]$ state [30]. This may also hold for the ^{169}W ground-state assignment. However, in in-beam spectroscopy the lowest observed $\frac{5}{2}^-[523]$ state is the $\frac{7}{2}^-$ rotational level, 47 keV below an $i_{13/2}$ intruder state [42]. Due to experimental restrictions, no energies below $\approx$ 100 keV were measured. Our α decay data propose a favored $\frac{5}{2}^-[523]\rightarrow\frac{5}{2}^-[523]$ decay. Thus, the 79 keV $M1$ γ transition could be described as depopulating the $\frac{7}{2}^-\frac{5}{2}^-[523]$ rotational state.

The $\frac{5}{2}^-[523]$ band is well known in neighboring nuclei of similar deformations, showing nearly the same rotational energies (which indicate a changing moment of inertia) over the whole region. These experimental level energies are compiled in Table V. If we apply our proposed identification, the similarity between the $\frac{5}{2}^-[523]$

TABLE V. Experimental level energies of the members of the rotational band built upon the $f_{7/2}\,\frac{5}{2}^-[523]_p$ single-particle state in nuclei around ^{165,167}W. The energies are given relative to the $\frac{5}{2}^-[523]$ bandhead.

Isotope	^{165}Hf	^{171}Os	^{173}Os	^{167}W	^{169}W	^{171}W
Ref.	[45]	[30]	[30]	[42]	[46]	[47]
I			energy [keV]			
7/2	76	76.9	91.8	x		102
9/2	219	208.0	219.7	136+x	y	233
11/2		445.9	388.8		145+y	389
13/2	531	602.1	534.8	474+x	327+y	548
15/2		896.1	721.0			736
17/2	955	1111.9	889.7	944+x	734+y	915
19/2		1402.2	1092.9			1131
21/2	1436	1645.5	1289.4		1176+y	1332

band in ^{167}W and in neighboring nuclei, especially in ^{165}Hf and ^{171}Os, is striking.

In in-beam investigations of ^{165}W only the $i_{13/2}$ state has been identified so far [43]. From the systematics of Table V, the 72 keV transition in ^{165}W is likely to play the same role as the 79 keV transition in ^{167}W. Furthermore, the $\frac{5}{2}^-$[523] was identified as a ground state in ^{165}W due to its β decay into excited states in ^{165}Ta [7]. Then, according to its α feeding and to the measured 43 keV $M1$ multipolarity, the spin of the 43 keV level is $\frac{3}{2}^-$ or $\frac{7}{2}^-$. From the Nilsson systematics, the $\frac{5}{2}^-$[523] and $\frac{3}{2}^-$[521] neutron states are expected near the Fermi level in ^{165}W. Thus, a $\frac{3}{2}^-$[521] assignment of this state is proposed. An additional argument in favor of this Nilsson characterization is given by the fact that the $\Delta\ell = 1$ α decay with lower decay energy is stronger in intensity. This can be explained by its feeding of a nuclear state with the same Nilsson quantum numbers as the decaying $\frac{5}{2}^-$[523] configuration in ^{169}Os.

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