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DDECAY OF Re^{188}

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Abstract: The gamma rays in Os^{188} following beta decay of 18-h Re^{188} have been studied using coincidence and directional correlation techniques The results agree with the principal features of the decay scheme proposed by Johns *et al* [1]) A number of new, weak transitions are observed and an additional level is proposed at 1.750 MeV Directional correlation measurements were made on six cascades From the directional correlation measurements, spins 2, 2, 0, 2, 0, 2 are assigned to the levels at 0 155 MeV, 0 633 MeV, 1 086 MeV, 1.461 MeV, 1 765 MeV and 1 941 MeV, respectively The 0 478-MeV gamma ray is a dipole-quadrupole mixture with $Q \leqq 99$ % The 0 828-MeV and 1 308-MeV gamma rays are pure dipole

1. Introduction

The decay of 18-h Re^{188} to levels in Os^{188} has been studied by a number of investigators [1–7]) †††. Johns *et al.* [1]) have proposed a decay scheme on the basis of external conversion and coincidence measurements. Os^{188} is on the edge of a region in which the nuclei exhibit a well-defined rotational structure ($155 \leqq A \leqq 185$). A 4+ state has recently been found at 0.479 MeV in Os^{188} fed by the decay of Ir^{188} [8, 9]). It appears that this nucleus does exhibit some rotational structure, and it is hoped that some of the higher excited levels can be related through the unified model.

2. Experimental Procedure

Samples of spectroscopically pure rhenium metal were irradiated at a flux of 2×10^{12} neutrons/cm$^2 \cdot$ sec for periods of 2 to 6 hours in the Ford Nuclear Reactor. The sources used in the coincidence and directional correlation measurements consisted of irradiated rhenium powder dissolved in nitric acid and diluted. The only observed impurity was the 91-h Re^{186}. Data for the 0.478-MeV—0.155-MeV directional correlation were taken during the first few hours after irradiation in order to minimize possible interference from the very

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††† Since completion of the present research, a report has appeared [13]) which describes directional correlation measurements leading to spin assignments in agreement with the present work.

weak 0.631-MeV—0.137-MeV cascade in Re^{186}. The 91-hour activity did not interfere with any of the other measurements.

The coincidence measurements employed a fast-slow coincidence circuit with a resolving time of 30 ns. Pulses coincident with a selected energy range were fed through a linear gate and recorded on a 256-channel analyzer.

A fast-slow coincidence circuit with a resolving time of 18 ns was used in the directional correlation measurements. The detectors in all cases consisted of 2-in. by 2-in. NaI(Tl) crystals mounted on RCA 6342 or 6342A phototubes. Differential analyzers provided energy selection in the directional correlation measurements. Lateral lead shield was used to prevent counter-to-counter scattering. Data were taken in a double-quadrant sequence at seven angles (i.e., every 15°) in each quadrant. The real coincidence rate was corrected for source decay and electronic drift. After making a least squares fit [10]), the expansion coefficients were normalized and corrected for finite resolution [11]).

3. Results

3 1. COINCIDENCE MEASUREMENTS

Fig. 1 shows the gamma ray spectrum of Re^{188} as recorded on the multichannel analyzer. The observed width of the 1.610-MeV and 1.79-MeV photopeaks indicates that these transitions are complex.

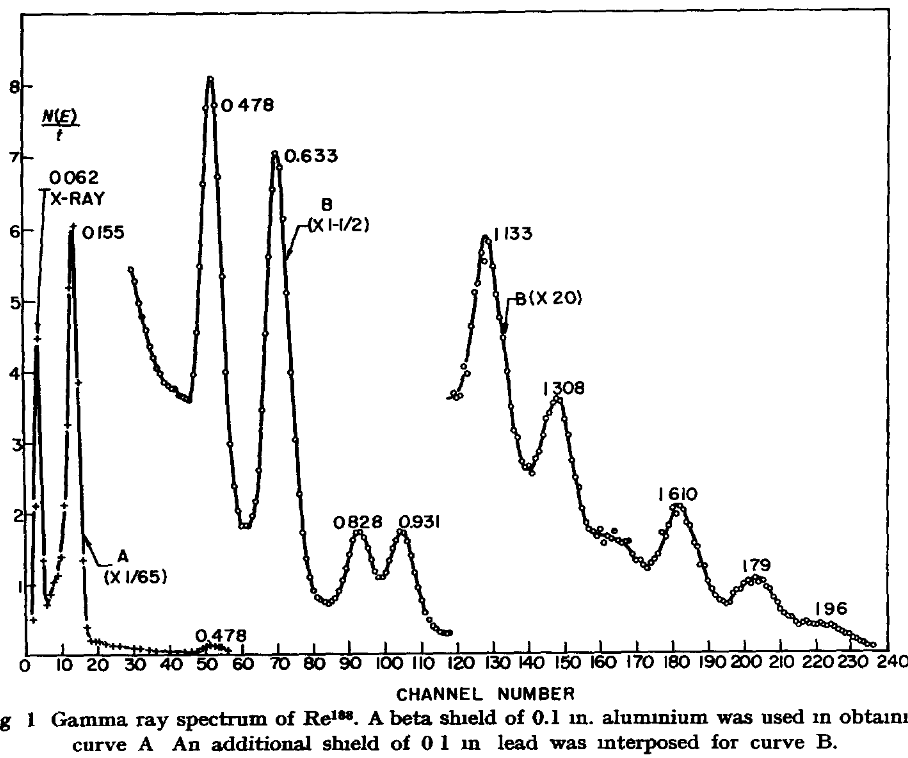

Fig 1 Gamma ray spectrum of Re^{188}. A beta shield of 0.1 in. aluminium was used in obtaining curve A An additional shield of 0 1 in lead was interposed for curve B.

Measurements were made of the spectrum of gamma rays in coincidence with the 0.155-MeV, 0.478-MeV, 0.633-MeV and 0.828-MeV photopeaks. Fig. 2 shows the spectrum of gamma rays coincident with the 0.155-MeV photopeak. A complex peak is found which is made up of the 0.633-MeV and 0.673-MeV transitions. The weak 0.633-MeV and 0.155-MeV peaks are due to the presence of the Compton distribution of higher-energy gamma rays beneath the 0.155-MeV photopeak in the range-selecting channel. The observed complexity of the 1.133-MeV photopeak is attributed to the presence of a weak 1.151-MeV

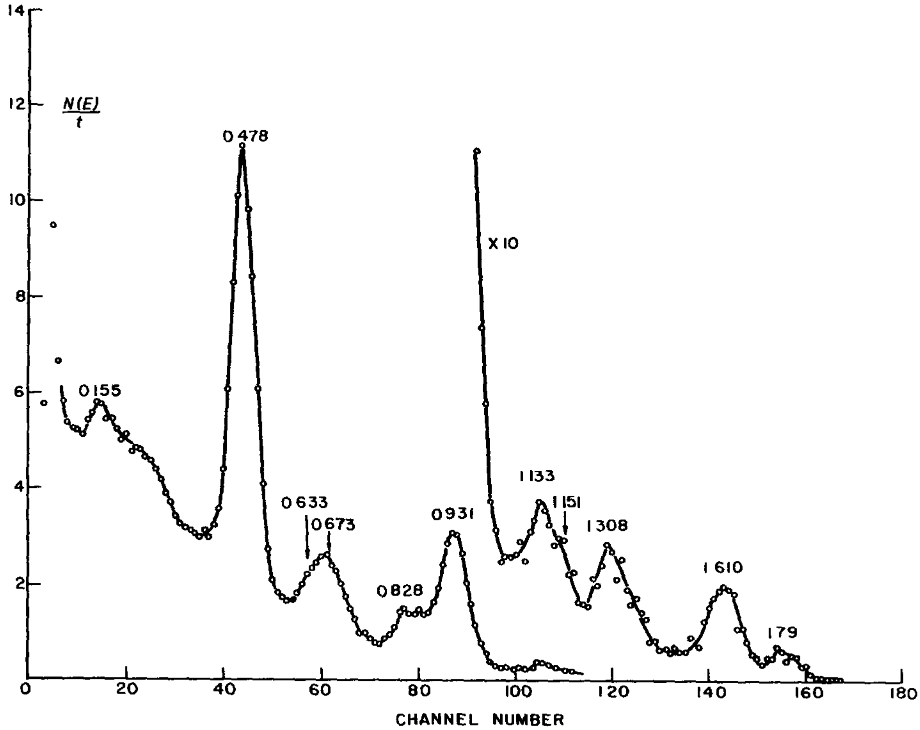

Fig. 2 Spectrum of gamma rays coincident with the 0.155-MeV photopeak. The detector which selected the 0 155-MeV gamma ray was shielded with aluminium to eliminate beta particles. An additional shield of 0 1 in. lead was used for the analyzed detector.

transition between the 1 306-MeV level and the 0.155-MeV level. The 1.609-MeV photopeak also appears to be complex. This is probably due to weakly-fed level ≈ 0.015 MeV below the 1.765-MeV level. Additional evidence for a second level will be discussed in regard to the 1.133-MeV —0.633-MeV directional correlation measurement and as a result of the 0.828-MeV coincidence spectrum. The complexity of the peak at 1.79 MeV has been explained by Johns *et al.* [1]). Two gamma rays are present with energies of 1.783 MeV and 1.803 MeV.

Fig. 3 illustrates the spectrum of gamma rays coincident with a narrow range of the 0.633-MeV photopeak. Curve B is the observed coincidence spectrum after subtraction of interference due to the Compton distribution of higher-energy gamma rays beneath the 0.633 MeV peak. The 0.673-MeV photopeak is clearly resolved. The photopeak at 0.480 MeV suggests a weak transition of this energy (in addition to the 0.478-MeV gamma ray), probably between the 1.941-MeV and 1.461-MeV levels. The 1.133-MeV photopeak is wider than would be expected for a single gamma ray.

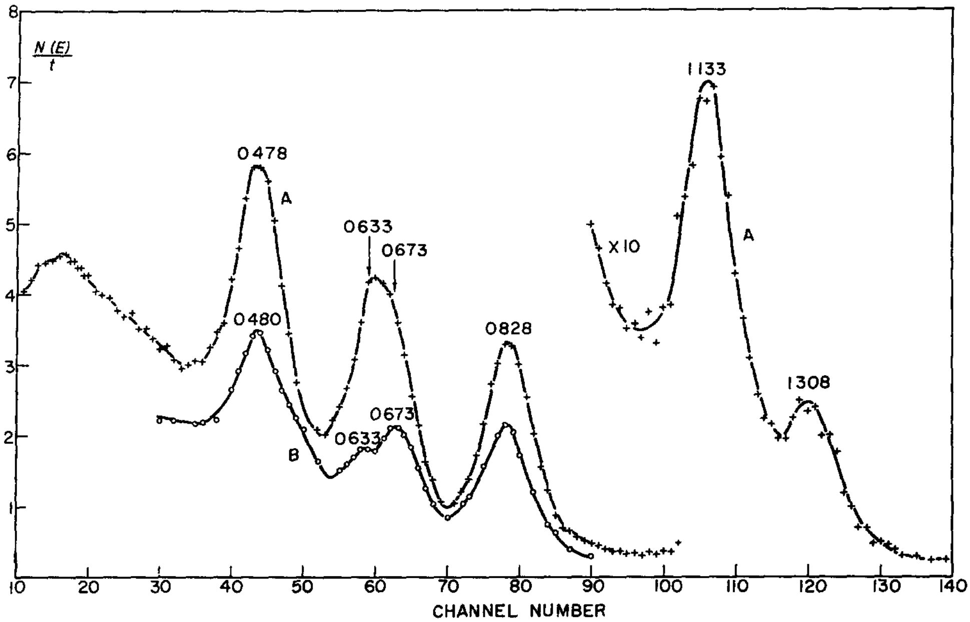

Fig 3 Spectrum of gamma rays coincident with the 0 633-MeV photopeak. Both detectors were shielded with 0.1 in each of aluminium and lead Curve A is the observed coincidence spectrum Curve B is a similar spectrum after subtraction of interference due to Compton distributions from higher-energy gamma rays beneath the 0 633-MeV photopeak

The spectrum of gamma rays in coincidence with the 0.828-MeV photopeak is shown in fig. 4. Curve A shows a portion of this coincidence spectrum obtained with detectors shielded to eliminate beta particles. Two new gamma rays are observed at 0.209 MeV and 0.288 MeV. The 0.209-MeV transition is interpreted as a transition from the 1 958-MeV level to a new level at 1.750 MeV. The 0.288-MeV gamma ray is a transition from the 1.750-MeV level to the 1.461-MeV level These transitions were also observed in a spectrum of gamma rays coincident with the 0.633-MeV photopeak. Curve B was obtained with 0.1 in. lead shielding in addition to the beta shield. The peak at 0.478 MeV is relatively stronger in this spectrum than in the single spectrum when compared with the

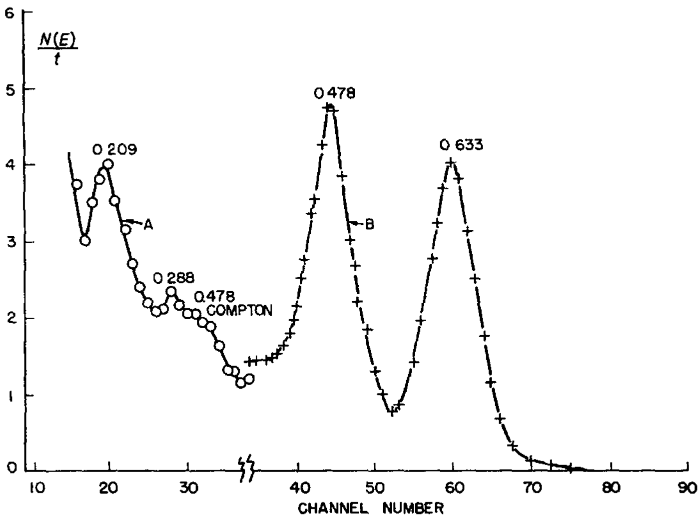

Fig 4. Spectrum of gamma rays coincident with the 0 828-MeV photopeak Curve A was recorded with 0 1 in of aluminium on the detectors to absorb beta particles For curve B an additional 0 1 in of lead was added to the shielding The curves are not drawn to the same scale

TABLE 1

Relative intensities of the gamma rays of Re^{188}

E (MeV)	Intensity
0 155	7 2 [a]
0 209	0 03
0 288	0 008
0 454	0 02
0 478 [b]	0 62
0 633	1 00
0 673	0 14
0 828	0 35
0 931	0 46
1 133 [b]	0 086
1 151	0 003
1.306	0 007
1 308	0 040
1 610 [b]	0 046
1 783 } 1 805 }	0 024
1 959	0 022

[a] Unconverted gamma ray intensity.
[b] Complex.

The intensities have been normalized to the 0 633-MeV transition. An accuracy of ± 10 % is expected for the strong transitions. The uncertainty may be considerably larger for the weak gamma rays.

0.633-MeV peak. This attests to the relative weakness of the 0.454-MeV transition compared to the 0.673-MeV transition

The spectrum of coincidences with the 0.478-MeV peak (not shown) indicates the presence of a weak peak at 0.454 MeV as proposed by Johns *et al.* in addition to the other gamma rays expected.

The results of the coincidence measurements are summarized in table 1. The proposed relative intensities were measured from the scintillation spectrometer curves and have been corrected for efficiency and correlation effects.

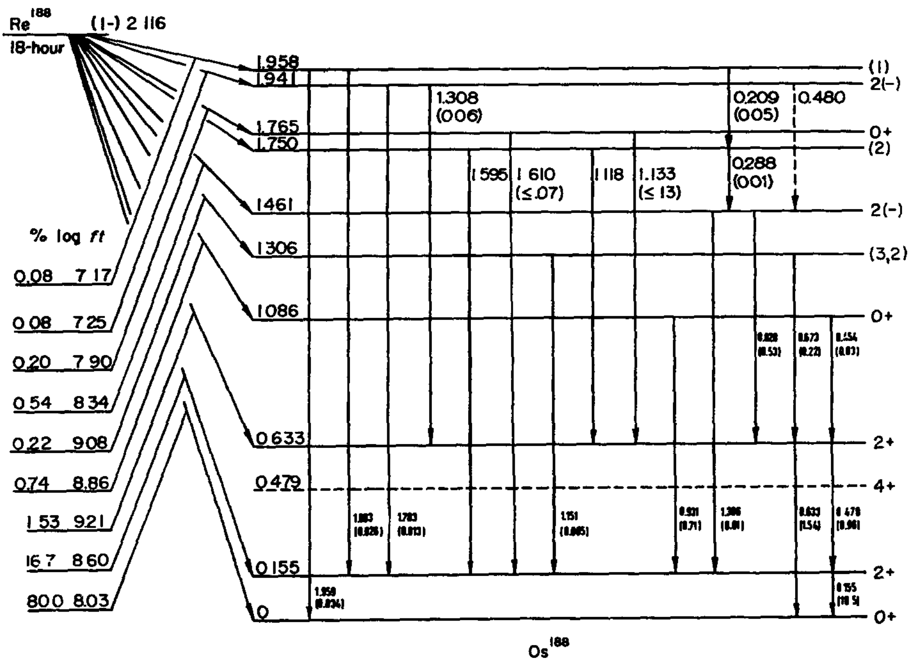

Fig. 5. Decay scheme of Re[188]. The energies (in MeV) are taken from Johns *et al* [1]). The relative intensities (in percent) are the result of the present measurements

The proposed decay scheme is shown in fig. 5. It agrees with the scheme of Johns *et al.* with the exception of some possible weak transitions and an additional level at 1.750 MeV. The log *ft* values quoted have been calculated from the observed gamma-ray branching, making use of the known ground-state beta intensity and conversion coefficients for the 0.155-MeV gamma ray [1]).

3.2. DIRECTIONAL CORRELATION MEASUREMENTS

0 828-MeV — 0 633-MeV CASCADE

This directional correlation was measured by accepting a narrow range of pulses on the 0.828-MeV photopeak in one differential analyzer and the full photopeak of the 0.633-MeV gamma ray in the other differential analyzer.

With this arrangement, about 14.5±1.5 % of the real coincidences observed result from the 1.133-MeV — 0.633-MeV and 1.308-MeV — 0.633-MeV cascades. The interference was measured and subtracted from the observed correlation function. The resultant expansion coefficients, after correction for finite angular resolution, were found to be $A_2 = +0.245 \pm 0.016$, $A_4 = 0$.

Assuming that the 0.633-MeV gamma ray is pure 2(Q)0, these coefficients are in good agreement with the theoretical coefficients of a pure 2(D)2(Q)0 sequence, $A_2 = +0.250$, $A_4 = 0$. The error limits will allow a quadrupole content of no more than $Q = 0.001$ in the 0.828-MeV gamma ray. The coefficients will not fit sequences of the form 3(D, Q)2(Q)0 or 1(D, Q)2(Q)0.

1 308-MeV – 0 633-MeV and 1 133-MeV – 0 633-MeV CASCADES

Although the 1.308-MeV and the 1.133-MeV photopeaks were easily resolved by the scintillation counters, there remained a slight overlap of these lines which was considered in analyzing the directional correlation data. Two directional correlation measurements were made. In both cases one differential analyzer was set to accept the full photopeak of the 0.633-MeV gamma ray. In one case the second differential analyzer was set on the 1.308-MeV photopeak and in the other case it was set on the 1.133-MeV photopeak.

Using the relative intensities measured in the coincidence experiments, the pair of peaks was constructed from known shapes of single gamma rays in this region. The contribution of both gamma rays to each correlation function was then determined. The two correlation functions were combined with special attention to the errors in the relative intensities, and channel settings. In this manner the 1.133-MeV—0.633-MeV cascade yielded corrected expansion coefficients of $A_2 = +0.150 \pm 0.046$, $A_4 = +0.702 \pm 0.060$. The observed A_4 coefficient is too large to allow a spin assignment of 2 to the 1.765 level. Thus the spin of this level must be zero, although the observed coefficients do not agree well with the theoretical coefficients for a 0(Q)2(Q)0 sequence, i.e., $A_2 = +0.3571$, $A_4 = +1.143$. The source was in solution and no attenuation is expected to be present. Potnis *et al.* [4]) observed the full correlation for the 0.478-MeV—0.155-MeV cascade using a metallic source. The lifetime of the 0 633-MeV level is expected to be shorter than that of the 0.155-MeV level and this, together with the fact that the full correlation is observed for other cascades involving the 0.633-MeV level, tends to rule out a perturbation due to extranuclear fields. The present discrepancy can be explained if it is assumed that another level lies close to the 1.765-MeV level and decays via an unresolved gamma ray with energy near 1.133 MeV. This lends strong support to the existence of the level proposed at 1.750 MeV as a result of the coincidence measurements. The presence of the new level does not change the fact that the 1.765-MeV level must be assigned a spin of zero.

In the manner described above, the corrected expansion coefficients for the

1.308-MeV—0.633-MeV cascade were found to be $A_2 = +0.309 \pm 0.065$, $A_4 = +0.044 \pm 0.089$. These coefficients agree well with the theoretical coefficients for a 2(D)2(Q)0 cascade, namely $A_2 = +0.25$, $A_4 = 0$. If this sequence is of the form 2(D, Q)2(Q)0, the coefficients limit the quadrupole content of the 1.308-MeV transition to $Q \leqq 0.035$. The experimental coefficients will also fit a 3(D, Q)2(Q)0 sequence if the quadrupole content is in the range $Q = 0.42 \pm 0.13$. This degree of mixing is highly improbable and therefore the 1.941-MeV level is assigned a spin 2.

0.931-MeV — 0.155-MeV CASCADE

In this directional correlation the window of one differential analyzer was set to accept the 0.155-MeV photopeak. The second analyzer was set to accept a narrow range of pulses on the upper portion of the 0.931-MeV photopeak. With this arrangement a small fraction of the real coincidences accepted were due to 0.828-MeV—0.155-MeV cascade and an additional small interference resulted from coincidences of the 0.155-MeV gamma ray with the Compton distributions of higher-energy gamma rays beneath the 0.931-MeV gamma ray. The interfering correlations were measured and subtracted from the observed coefficients. After correction for finite angular resolution, the expansion coefficients were found to be $A_2 = 0.35 \pm 0.05$, and $A_4 = +1.06 \pm 0.17$. These are in good agreement with the theoretical coefficients for a 0(Q)2(Q)0 sequence, i.e., $A_2 = +0.3571$ and $A_4 = +1.143$. The observed coefficients will not fit any other spin sequence.

0.478-MeV—0.155 MeV CASCADE

For this cascade, each of the differential analyzers was allowed to accept the full-energy peak of one of the gamma rays. Due to the complexity of the decay, a significant portion of the real coincidences accepted were due to other cascades which were measured and subtracted from the basic correlation function. This yielded corrected expansion coefficients of $A_2 = -0.079 \pm 0.054$ and $A_4 = +0.402 \pm 0.083$. These coefficients will fit a 2(D, Q)2(Q)0 sequence with a large ($Q \geqq 0.99$) quadrupole content in the first transition. There appears to be good evidence for other gamma rays at energies near 0.478 MeV in coincidence with the 0.155-MeV transition. Hence, the quadrupole content derived above may be somewhat in error, although the spins of the 0.633-MeV and 0.155-MeV levels are certainly 2. Neither of the previous directional correlation measurements on this cascade [4,7]) took the interference into consideration.

0.673-MeV — 0.633-MeV CASCADE

A directional correlation measurement was attempted on the weak 0.673-MeV—0.633-MeV cascade. However, the interference from other cascades is quite large as can be seen from fig. 3, curve B. This results in large errors on the expansion coefficients. Within these limits, the expansion coefficients were consistent with a spin 3 or 2 for the 1.306-MeV level in agreement with the observed gamma ray branching.

4. Summary and Discussion

As a result of directional correlation measurements, spins 2, 2, 0, 2, 0 and 2 have been assigned to the levels at 0.155 MeV, 0.633 MeV, 1.086 MeV, 1.461 MeV, 1.765 MeV and 1.941 MeV, respectively. The transition from the second 2+ state to the first excited state (spin = 2+) has been shown to be mostly E2 with a small M1 admixture. A 4+ state has recently been found at 0.479 MeV (fed from Ir^{188}, [8, 9]). This state and the first excited state are interpreted as members of the ground-state rotational band

As a result of the directional correlation measurements, it has been shown that the 1.308-MeV and 0.828-MeV gamma rays are nearly pure dipole transitions from spin 2 states to the 2+ level at 0.633 MeV. If the de-excited levels have positive parity, the resultant gamma rays must be M1 in character, which is contrary to the interpretation of these levels as collective excitations. If negative parity is assumed, the calculated log *ft* values for beta decay to the 1.941-MeV and 1.461-MeV levels, viz., 7.25 and 8.34, are larger than would be expected.

The second 2+ state at 0.633 MeV may be considered as a member of the ground-state rotational band in terms of the interpretation of the unified model due to Davydov and Filippov [12]). Many of the high-energy gamma rays observed following the decay of Ir^{188} do not occur in the decay of Re^{188}. This indicates that a different set of levels are fed by the two decays. An attempt to interpret the higher excited states of Os^{188} may be more reasonable when more is known concerning the levels fed from Ir^{188}.

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