ISSN 1330–0016
CODEN FIZBE7

TWO-STEP CASCADES OF THE ^{185}W COMPOUND NUCLEUS γ-DECAY

VALERY A.BONDARENKO[a], JAROSLAV HONZÁTKO[b], VALERY A. KHITROV[c], ANATOLY M. SUKHOVOJ[c] and IVO TOMANDL[b]

[a]*Institute of Solid State Physics, University of Latvia, LV 2169 Salaspils, Latvia*

[b]*Nuclear Physics Institute, CZ-25068 Řež near Prague, Czech Republic*

[c]*Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research, 141980 Dubna, Russia*

Received 27 June 2002; Accepted 17 January 2003
Online 7 February 2003

Two-step cascades from the $^{184}\mathrm{W}(\mathrm{n_{th}},\gamma)^{185}\mathrm{W}$ reaction were studied in a $\gamma-\gamma$ coincidence measurement. The total intensity of cascades terminating at levels with the energy ≤ 2.2 MeV was estimated for the first time. The decay scheme of ^{185}W including 781 cascades was established up to the excitation energy $\simeq 3.3$ MeV. As in the nuclei studied earlier, the excitation spectrum of intermediate levels of the most intense cascades was found to be harmonic.

PACS numbers: 25.40.Lw, 27.70.+q UDC 539.172.4

Keywords: $^{184}\mathrm{W}(\mathrm{n_{th}},\gamma)^{185}\mathrm{W}$ reaction, two-step γ-cascades, decay scheme of ^{185}W, harmonic excitation spectrum of intermediate levels

1. *Introduction*

Nuclear properties in the excitation interval up to the neutron binding energy B_n undergo a radical change; the simplest low-lying levels transform into the Bohr's compound states. The only possibility to study this process in details is provided by the experimental investigation of the two-step γ-cascades proceeding between the neutron resonance and a group of low-lying levels. The two-step cascades to the low-lying levels of a nucleus under study give rich and reliable information on the excited states and modes of their γ-decay, even without involving complementary spectroscopic data. The use of the maximum likelihood method to extract primary transitions [1] with equal energy in different cascades allows one to obtain reliable decay scheme and to quantitatively estimate the probability of false levels in it [2]. The analysis of the cascade intensities, averaged over some interval of the excitation energy region of the cascade intermediate levels, is inaccessible by other methods for the data on the properties of heavy nuclei at $E_{\mathrm{exc}} \geq 1$ up to 3 MeV.

2. *Experiment*

Two-step γ-cascades following thermal neutron capture in ^{184}W were studied by γ-γ coincidence measurements undertaken at the LWR-15 reactor in Řež. The measurements were performed using the spectrometer [3] consisting of two HPGe-detectors with the efficiency 25% and 28% for ^{60}Co γ-rays of 1.332 MeV. The target consisting of 1100 mg of ^{184}W, 17 mg of ^{182}W, 32 mg of ^{183}W and 38 mg of ^{186}W was used. According to the thermal neutron cross sections [4], this target provided 9%, 8%, 47% and 36% captures in ^{182}W, ^{183}W, ^{184}W and ^{186}W, respectively. However, a sufficiently high efficiency of detectors and fine energy resolution (*FWHM* $\simeq 5$ keV for peaks at $E_c = 5 - 6$ MeV in the sum coincidence spectrum) allowed us to obtain the results of acceptable quality in this case, as well.

The main part of the sum coincidence spectrum measured in the experiment is shown in Fig. 1. Statistics of useful events for the cascades with the highest energy

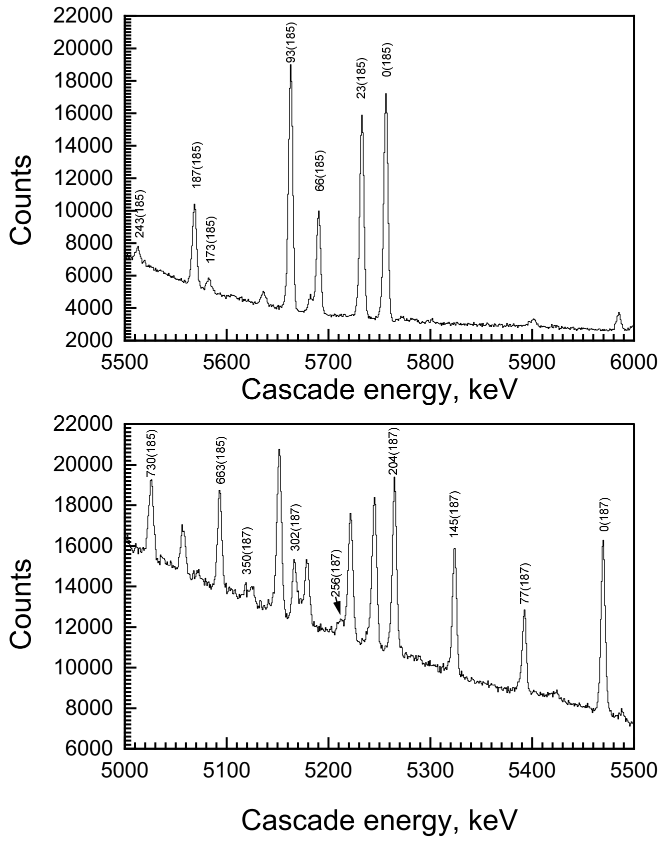

Fig. 1. The part of the sum coincidence spectrum for the target enriched in ^{184}W. *The peaks are labelled with the energy (in* keV*) of final cascade levels. The mass of the corresponding isotope is given in brackets.*

in this experiment is several tens times higher than that in earlier experiments in Dubna [5,6]. This permitted us to get the intensity distributions of a high quality for the cascades with $E_1 + E_2 = B_n - E_f$ as functions of energy of one of the transitions. On the whole, there were 5, 6, 16 and 5 distributions in ^{183}W, ^{184}W, ^{185}W and ^{187}W, respectively. As an example, one of them is shown in Fig. 2.

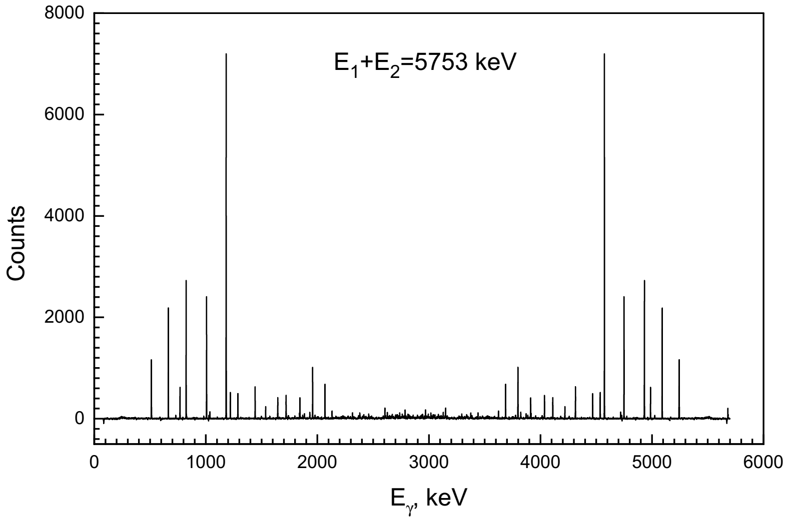

Fig. 2. The intensity distribution of the two-step cascades terminating at the ground state of ^{185}W *(after the procedure for improving the energy resolution).*

Each two-step cascade in a such spectrum is presented by a pair of peaks with equal areas and widths [7]. Energy resolutions in each of these distributions is varying between 1.5 keV at their ends and 2.4 keV in the center. The probability of observing a low-intensity cascade is determined only by the amplitude of the "noise" line which increases as the background under the peaks in the sum coincidence spectrum increases. Therefore, the registration threshold, L_c, for individual cascades was determined from an analysis of spectra $E_c = const$ corresponding to the background intervals in the sum coincidence spectrum. It was established that L_c increases from 1 to 3 events per 10^4 decays as the cascade energy changes from 5.8 to 4.7 MeV.

3. Spectroscopic information

The method of construction of a decay scheme using the obvious thesis about the constancy of the energy $E_1 = B_n - E_i$ of the primary transition in the cascades with the different total energy $E_1 + E_2 = const$ was described for the first time in Ref. [1]. The method uses multi-dimensional Gauss distribution in the framework of the maximum likelihood method in order to select probable γ-transitions with equal energy in different spectra. As it was shown in Ref. [2], the algorithm gives reliable results even at the mean error in determination of E_1 up to $\simeq 1.5$ keV and about 350 cascades resolved in the spectrum as the pairs of peaks are placed into the decay scheme. Corresponding decay scheme for ^{185}W is given in Table 1.

TABLE 1. A list of absolute intensities (per 10^2 decays), $i_{\gamma\gamma}$, of measured two-step cascades, and energies, E_1 and E_2, of the cascade transitions. E_i are the energies of intermediate levels. Only statistical uncertainties of determination of energies and intensities are given (in parentheses). The lower estimates of $i_{\gamma\gamma}$ for cascades with $E_1 < 520$ keV or $E_2 < 520$ keV are listed. All energies are in keV.

E_1	E_i	E_2	$i_{\gamma\gamma}$
5090.60	663.10(10)	663.10	0.790(13)
		639.54	0.792(13)
		597.22	0.444(13)
		569.79	0.832(18)
		475.20	0.192(16)
		419.40	0.452(13)
5024.10	729.60(10)	729.60	0.024(3)
		706.04	0.073(4)
		663.72	0.088(5)
		636.29	0.119(8)
		485.90	0.043(3)
4986.00	767.70(5)	767.70	0.219(7)
		744.14	0.408(9)
		701.82	0.063(5)
		674.39	0.259(10)
4931.10	822.60(10)	822.60	1.043(17)
		799.04	0.031(4)
		756.72	0.617(13)
		729.29	0.036(4)
4926.70	827.00(20)	803.44	0.032(4)
		733.69	0.031(4)
4836.20	917.50(20)	917.50	0.010(3)
		824.19	0.028(3)
4785.90	967.80(10)	944.24	0.143(7)
		901.92	0.042(4)
		874.49	0.049(5)
		779.90	0.114(12)
4774.40	979.30(40)	913.42	0.006(2)
		791.40	0.046(8)
4748.10	1005.60(5)	1005.60	0.901(19)
		982.04	0.156(6)
		939.72	0.093(5)
		912.29	2.692(38)
4717.90	1035.80(20)	1035.80	0.047(4)
		1012.24	0.036(4)
		942.49	0.104(8)
		847.90	0.014(6)
4712.00	1041.70(20)	948.39	0.066(6)
		868.00	0.006(1)
4685.50	1068.20(44)	1044.64	0.031(4)
		974.89	0.066(6)
		894.50	0.004(1)
4676.40	1077.30(18)	903.60	0.004(1)
4666.90	1086.80(17)	913.10	0.004(1)
4652.30	1101.40(40)	1101.40	0.012(3)
		1077.84	0.045(4)
		1008.09	0.071(8)
		927.70	0.016(1)
4608.40	1145.30(16)	1121.74	0.015(3)
4606.30	1147.40(25)	903.70	0.019(5)
4572.30	1181.40(10)	1181.40	2.761(26)
		1157.84	1.098(26)
		1115.52	0.322(12)
		1088.09	0.607(21)
		517.80	0.531(58)
		451.40	0.958(35)
		353.90	0.109(12)
4534.70	1219.00(10)	1219.00	0.213(8)
		1195.44	1.122(26)
		1153.12	0.569(12)
		1125.69	1.404(32)
		1031.10	0.877(23)
		975.30	0.214(23)
		555.40	0.174(35)
		391.50	0.032(4)
4469.50	1284.20(22)	554.20	0.037(8)
4467.10	1286.60(10)	1286.60	0.190(8)
		1263.04	0.074(4)
		1220.72	0.044(4)
		1193.29	0.088(6)
		1098.70	0.187(11)
		556.60	0.093(12)
4441.10	1312.60(30)	1312.60	0.007(2)
4426.00	1327.70(33)	1327.70	0.006(2)
4400.30	1353.40(35)	1353.40	0.006(2)
4383.70	1370.00(30)	1304.12	0.007(3)
		1276.69	0.007(3)
4352.70	1401.00(22)	1307.69	0.011(3)
4312.50	1441.20(30)	1441.20	0.242(7)
		1417.64	0.761(17)
		1375.32	0.009(3)
		1347.89	0.431(10)
		672.81	0.100(11)
		613.70	0.064(5)
4310.60	1443.10(20)	1419.54	0.121(13)
		1377.22	0.018(3)
4257.30	1496.40(10)	1496.40	0.021(3)
		1472.84	0.067(4)
		1430.52	0.016(3)
		1403.09	0.120(5)
		1308.50	0.027(4)
4249.80	1503.90(20)	1410.59	0.017(3)
		840.30	0.072(9)
4218.40	1535.30(11)	1535.30	0.087(5)

Table 1. (cont.)

E_1	E_i	E_2	$i_{\gamma\gamma}$
		1511.74	0.075(4)
		1469.42	0.008(3)
		1441.99	0.017(3)
		871.70	0.622(25)
		805.30	0.562(27)
		707.80	0.160(11)
		617.70	0.063(17)
4191.30	1562.40(20)	1538.84	0.009(3)
		1469.09	0.103(5)
4183.10	1570.60(16)	840.60	0.077(12)
4181.10	1572.60(20)	1572.60	0.019(3)
		1549.04	0.020(3)
		1506.72	0.024(3)
		1479.29	0.010(3)
		1398.90	0.002(1)
		1328.90	0.018(3)
		842.60	0.057(11)
		745.10	0.025(7)
4176.60	1577.10(35)	913.50	0.027(8)
4140.90	1612.80(20)	1546.92	0.012(3)
		1369.10	0.149(7)
		949.20	0.049(9)
4109.80	1643.90(30)	1643.90	0.169(7)
		1620.34	0.031(3)
		1578.02	0.014(3)
		1550.59	0.010(3)
		1456.00	0.016(4)
		816.40	0.067(6)
4103.30	1650.40(16)	822.90	0.031(6)
4095.30	1658.40(58)	1658.40	0.011(3)
		1634.84	0.007(3)
		1565.09	0.043(3)
		1470.50	0.006(2)
4083.70	1670.00(20)	1604.12	0.008(3)
4079.70	1674.00(20)	1650.44	0.132(7)
		1608.12	0.070(5)
		1580.69	0.010(3)
		1486.10	0.072(4)
		944.00	0.022(4)
		851.23	0.025(6)
4069.80	1683.90(21)	1660.34	0.014(3)
4066.90	1686.80(31)	1513.10	0.003(1)
4064.00	1689.70(20)	1596.39	0.006(3)
		1026.10	0.020(9)
4059.00	1694.70(21)	1031.10	0.046(9)
4036.90	1716.80(35)	1528.90	0.012(4)
4035.00	1718.70(20)	1718.70	0.189(8)
		1695.14	0.034(4)
		1652.82	0.165(6)
		1625.39	0.098(5)
		1545.00	0.016(2)
		1530.80	0.057(5)
		1055.10	0.031(9)
		950.31	0.119(8)
		891.20	0.080(6)
4024.80	1728.90(65)	1728.90	0.011(3)
		1541.00	0.006(2)
4018.60	1735.10(8)	912.33	0.061(8)
4014.30	1739.40(39)	1739.40	0.028(11)
4006.80	1746.90(29)	1573.20	0.003(1)
4000.10	1753.60(34)	1660.29	0.008(3)
3979.00	1774.70(20)	1751.14	0.014(3)
		1681.39	0.012(3)
		1586.80	0.017(2)
3958.40	1795.30(20)	1771.74	0.007(4)
		1065.30	0.079(6)
3956.40	1797.30(30)	1797.30	0.016(3)
		1773.74	0.060(5)
		1731.42	0.062(4)
		1703.99	0.104(5)
		1623.60	0.009(1)
		1609.40	0.044(3)
		1133.70	0.043(9)
		1028.91	0.013(4)
		974.53	0.022(5)
		969.80	0.023(4)
3927.60	1826.10(43)	1638.20	0.007(3)
3914.60	1839.10(20)	1839.10	0.044(4)
		1815.54	0.188(7)
		1773.22	0.079(5)
		1745.79	0.028(3)
		1651.20	0.022(3)
		1595.40	0.029(3)
		1175.50	0.036(7)
		1070.71	0.038(5)
		1016.33	0.015(4)
3911.30	1842.40(60)	1842.40	0.168(7)
		1818.84	0.077(5)
		1749.09	0.024(3)
		1654.50	0.014(3)
		1178.80	0.028(14)
		1112.40	0.056(5)
		1014.90	0.016(4)
3908.20	1845.50(10)	1845.50	0.017(3)
		1181.90	0.114(17)
3902.20	1851.50(40)	1851.50	0.008(3)
		1785.62	0.008(3)
		1187.90	0.044(8)
		1121.50	0.014(5)
		933.90	0.039(11)
3886.80	1866.90(96)	1866.90	0.027(3)
		1843.34	0.018(3)
		1044.13	0.040(7)
3870.80	1882.90(40)	1882.90	0.040(4)
		1817.02	0.053(4)
		1789.59	0.024(3)
		1695.00	0.068(4)
		1219.30	0.054(8)
		1152.90	0.047(5)
3865.50	1888.20(29)	1888.20	0.010(3)

Table 1. (cont.)

E_1	E_i	E_2	$i_{\gamma\gamma}$
3847.00	1906.70(43)	1906.70	0.006(3)
3831.80	1921.90(90)	1898.34	0.184(7)
		1734.00	0.007(3)
		949.30	0.037(10)
		1099.13	0.019(5)
3827.60	1926.10(104)	1926.10	0.012(3)
		1103.33	0.025(6)
3822.40	1931.30(20)	1931.30	0.052(4)
		1907.74	0.010(3)
		1837.99	0.008(3)
		1743.40	0.011(3)
3818.30	1935.40(36)	1935.40	0.007(3)
3804.30	1949.40(20)	1219.40	0.012(4)
		1181.01	0.040(5)
3800.80	1952.90(80)	1887.02	0.010(3)
		1859.59	0.023(3)
		1765.00	0.017(3)
		1222.90	0.021(4)
		1125.40	0.034(7)
3797.50	1956.20(50)	1956.20	0.434(11)
		1932.64	0.015(3)
		1890.32	0.013(3)
		1862.89	0.025(3)
		1768.30	0.025(3)
		1292.60	0.024(7)
		1226.20	0.042(4)
3781.40	1972.30(50)	1972.30	0.006(3)
3777.00	1976.70(62)	1976.70	0.025(4)
		1953.14	0.038(5)
		1910.82	0.015(3)
		1883.39	0.032(3)
		1313.10	0.038(5)
3774.20	1979.50(20)	1979.50	0.019(4)
		1913.62	0.012(3)
3769.10	1984.60(65)	1961.04	0.010(3)
		1157.10	0.024(7)
3762.30	1991.40(35)	1925.52	0.009(3)
3754.20	1999.50(50)	1999.50	0.011(3)
		1975.94	0.020(4)
		1906.19	0.008(3)
		1811.60	0.006(3)
3750.20	2003.50(31)	1815.60	0.009(3)
3746.70	2007.00(20)	2007.00	0.016(3)
		1941.12	0.011(3)
3744.20	2009.50(20)	1985.94	0.032(4)
		1279.50	0.054(4)
3715.70	2038.00(30)	2038.00	0.008(3)
		2014.44	0.016(3)
		1972.12	0.012(3)
		1850.10	0.007(3)
		1374.40	0.017(5)
3710.20	2043.50(20)	1977.62	0.006(3)
3691.60	2062.10(19)	1996.22	0.014(3)
3686.60	2067.10(20)	2067.10	0.278(9)
		2043.54	0.376(10)
		1973.79	0.145(6)
		1879.20	0.038(3)
		1403.50	0.119(7)
		1337.10	0.032(4)
		1298.71	0.095(6)
		1149.50	0.042(10)
3679.80	2073.90(20)	1980.59	0.019(3)
		1886.00	0.026(3)
3675.10	2078.60(30)	2012.72	0.015(3)
		1890.70	0.015(3)
		1255.83	0.035(5)
3672.20	2081.50(37)	2015.62	0.008(3)
3658.80	2094.90(36)	2029.02	0.008(3)
3656.20	2097.50(40)	2097.50	0.013(3)
		2031.62	0.007(3)
3644.80	2108.90(25)	2015.59	0.013(3)
3636.70	2117.00(28)	2093.44	0.011(3)
3631.00	2122.70(24)	2056.82	0.011(3)
3623.10	2130.60(10)	2130.60	0.073(4)
		2107.04	0.015(3)
		2037.29	0.044(4)
		1307.83	0.022(5)
3618.60	2135.10(31)	1312.33	0.012(4)
3615.50	2138.20(10)	2072.32	0.011(3)
		2044.89	0.011(3)
		1310.70	0.043(4)
3611.10	2142.60(20)	2049.29	0.026(4)
		1374.21	0.026(3)
3603.30	2150.40(80)	2150.40	0.007(3)
		2084.52	0.010(3)
		2057.09	0.011(3)
		1906.70	0.021(3)
		1382.01	0.010(3)
3599.90	2153.80(34)	2130.24	0.010(3)
3596.10	2157.60(24)	2134.04	0.014(3)
3592.70	2161.00(27)	2067.69	0.013(3)
3589.30	2164.40(20)	2164.40	0.016(3)
		2140.84	0.027(4)
		2071.09	0.019(3)
3575.30	2178.40(87)	2178.40	0.007(4)
		2154.84	0.100(6)
		2112.52	0.017(3)
		2085.09	0.047(5)
		1990.50	0.007(3)
		1355.63	0.012(4)
3567.20	2186.50(30)	2120.62	0.009(3)
		2093.19	0.022(4)
3562.50	2191.20(85)	2191.20	0.007(3)
		2097.89	0.038(4)
		1527.60	0.015(3)
3558.70	2195.00(80)	2101.69	0.010(3)
3547.40	2206.30(25)	2140.42	0.027(4)
3543.00	2210.70(30)	2187.14	0.032(4)
		2117.39	0.013(3)
		1383.20	0.012(3)

Table 1. (cont.)

E_1	E_i	E_2	$i_{\gamma\gamma}$
3536.80	2216.90(52)	2216.90	0.015(3)
		2123.59	0.053(5)
		2043.20	0.003(1)
3527.70	2226.00(20)	2226.00	0.022(3)
		2202.44	0.180(8)
		2160.12	0.010(3)
		2132.69	0.022(4)
		2038.10	0.041(5)
3520.50	2233.20(24)	2233.20	0.015(3)
3516.90	2236.80(10)	2236.80	0.012(3)
		2170.92	0.015(3)
		2143.49	0.020(4)
3512.80	2240.90(18)	2217.34	0.030(4)
		2175.02	0.008(3)
		2067.20	0.002(1)
3504.70	2249.00(30)	2249.00	0.012(3)
		2183.12	0.016(3)
3500.90	2252.80(30)	2229.24	0.025(7)
3498.90	2254.80(40)	2231.24	0.121(9)
		2188.92	0.013(3)
		2161.49	0.079(5)
		2081.10	0.002(1)
		2066.90	0.071(5)
		1591.20	0.014(4)
3485.60	2268.10(10)	2268.10	0.008(3)
		2244.54	0.069(6)
		2174.79	0.140(8)
		1604.50	0.022(4)
		1445.33	0.061(1)
		1350.50	0.065(10)
3478.50	2275.20(40)	2275.20	0.019(4)
		2209.32	0.011(3)
		1447.70	0.012(4)
3476.50	2277.20(20)	2277.20	0.012(4)
		2183.89	0.023(4)
3469.30	2284.40(50)	2260.84	0.021(4)
		2191.09	0.019(3)
		2096.50	0.009(3)
		1620.80	0.013(4)
		1461.63	0.016(1)
3465.30	2288.40(55)	2222.52	0.010(3)
		2100.50	0.007(3)
3461.20	2292.50(20)	2268.94	0.027(4)
		2199.19	0.031(4)
3458.80	2294.90(40)	2294.90	0.017(3)
		2201.59	0.029(4)
		2107.00	0.009(3)
3441.60	2312.10(10)	2288.54	0.020(4)
		2218.79	0.028(4)
		2124.20	0.016(4)
3438.60	2315.10(81)	2315.10	0.051(4)
		2249.22	0.007(3)
		2127.20	0.040(4)
		1651.50	0.016(4)
3426.40	2327.30(17)	2327.30	0.017(3)
3418.90	2334.80(55)	2334.80	0.012(3)
		2241.49	0.016(3)
3414.50	2339.20(10)	2339.20	0.008(3)
		2315.64	0.032(4)
		2273.32	0.015(3)
		2245.89	0.018(3)
		2151.30	0.013(3)
		2095.50	0.016(3)
		1675.60	0.014(4)
		1609.20	0.015(4)
3403.70	2350.00(21)	2326.44	0.019(4)
3400.40	2353.30(38)	1584.91	0.009(3)
3390.40	2363.30(34)	2297.42	0.009(3)
3386.00	2367.70(20)	2367.70	0.015(5)
		2344.14	0.018(4)
		2274.39	0.040(4)
		2179.80	0.056(4)
		1637.70	0.022(4)
		1599.31	0.027(3)
		1540.20	0.028(4)
3383.10	2370.60(80)	2370.60	0.022(5)
		2182.70	0.015(3)
3377.80	2375.90(70)	2282.59	0.066(4)
		2188.00	0.018(3)
		2132.20	0.007(3)
		1712.30	0.021(4)
		1553.13	0.018(4)
3374.00	2379.70(40)	2379.70	0.046(4)
		2286.39	0.169(6)
		2191.80	0.014(3)
		1649.70	0.039(4)
		1556.93	0.027(5)
		1552.20	0.041(4)
		1462.10	0.037(10)
3369.40	2384.30(50)	2384.30	0.012(3)
		2360.74	0.029(4)
		2290.99	0.035(4)
		1556.80	0.017(4)
		1466.70	0.193(10)
3362.70	2391.00(117)	2325.12	0.014(3)
		2297.69	0.008(3)
		2203.10	0.009(3)
3352.60	2401.10(108)	2401.10	0.010(3)
		2377.54	0.009(3)
		2335.22	0.040(4)
		2307.79	0.019(3)
3346.30	2407.40(52)	2407.40	0.022(3)
		2383.84	0.086(6)
		2341.52	0.024(4)
		2314.09	0.016(3)
		2233.70	0.002(1)
		2219.50	0.010(3)
		1743.80	0.013(4)
		1677.40	0.027(4)
		1584.63	0.034(5)

Table 1. (cont.)

E_1	E_i	E_2	$i_{\gamma\gamma}$
		1489.80	0.039(9)
3338.50	2415.20(40)	2415.20	0.027(4)
		1685.20	0.013(4)
		1592.43	0.013(4)
		1587.70	0.020(4)
3335.60	2418.10(30)	2418.10	0.011(3)
		2174.40	0.007(3)
3331.30	2422.40(28)	2422.40	0.012(3)
3328.70	2425.00(5)	2401.44	0.048(5)
		2359.12	0.038(4)
		2331.69	0.019(3)
3319.40	2434.30(22)	2434.30	0.016(3)
3313.80	2439.90(54)	2416.34	0.009(4)
3311.50	2442.20(60)	2442.20	0.007(3)
		2418.64	0.011(4)
		2376.32	0.014(3)
		2348.89	0.010(4)
3303.10	2450.60(40)	2427.04	0.018(3)
		2357.29	0.013(3)
3300.50	2453.20(50)	2453.20	0.011(3)
		2429.64	0.015(3)
		2359.89	0.020(3)
3294.40	2459.30(21)	2459.30	0.030(5)
3292.90	2460.80(40)	2460.80	0.019(5)
		2437.24	0.010(3)
		2367.49	0.014(3)
		1730.80	0.015(4)
		1638.03	0.031(5)
3287.40	2466.30(22)	2442.74	0.016(3)
3283.10	2470.60(115)	2470.60	0.008(4)
		2377.29	0.013(3)
		2282.70	0.008(2)
		1702.21	0.013(3)
3278.60	2475.10(30)	2475.10	0.013(4)
		2451.54	0.016(3)
		2409.22	0.009(3)
3274.00	2479.70(90)	2479.70	0.008(3)
		2456.14	0.049(5)
		2413.82	0.013(3)
		2386.39	0.020(3)
		1816.10	0.021(4)
3270.30	2483.40(36)	2483.40	0.016(5)
3268.40	2485.30(40)	2485.30	0.019(5)
		2461.74	0.025(4)
		2419.42	0.012(3)
		2391.99	0.018(3)
		2297.40	0.032(3)
		1755.30	0.012(3)
3253.90	2499.80(50)	2499.80	0.010(3)
		2433.92	0.010(3)
		2406.49	0.010(3)
3250.80	2502.90(20)	2479.34	0.019(3)
		2315.00	0.007(2)
3244.90	2508.80(14)	2415.49	0.029(4)
3240.30	2513.40(100)	2489.84	0.015(3)

E_1	E_i	E_2	$i_{\gamma\gamma}$
		2325.50	0.012(3)
3236.40	2517.30(25)	2493.74	0.013(3)
		2451.42	0.011(3)
		2329.40	0.019(3)
		2273.60	0.017(3)
3233.10	2520.60(58)	2497.04	0.033(4)
		2454.72	0.020(3)
		1697.83	0.015(4)
3225.50	2528.20(50)	2434.89	0.025(4)
		1705.43	0.012(4)
3205.60	2548.10(55)	2548.10	0.008(3)
		2524.54	0.008(3)
3201.80	2551.90(30)	2551.90	0.011(3)
3198.70	2555.00(39)	2489.12	0.007(3)
3193.70	2560.00(22)	2536.44	0.014(3)
		2494.12	0.015(3)
		2466.69	0.011(3)
		2372.10	0.038(3)
		1791.61	0.010(3)
3186.00	2567.70(46)	2474.39	0.011(4)
3179.00	2574.70(38)	2574.70	0.008(3)
		2551.14	0.076(6)
		2508.82	0.018(3)
		2386.80	0.015(2)
		1911.10	0.016(4)
		1844.70	0.015(4)
3176.00	2577.70(32)	1809.31	0.011(3)
3171.30	2582.40(10)	2582.40	0.008(3)
		2558.84	0.018(4)
		2489.09	0.073(5)
3163.60	2590.10(20)	2590.10	0.023(3)
		2566.54	0.027(4)
		2524.22	0.017(3)
3153.00	2600.70(40)	2600.70	0.008(3)
3149.10	2604.60(50)	2604.60	0.090(5)
		2581.04	0.022(4)
		2538.72	0.010(3)
		2511.29	0.025(4)
		2416.70	0.021(3)
		1836.21	0.016(3)
3143.90	2609.80(9)	2609.80	0.023(4)
		2586.24	0.023(4)
		2543.92	0.023(3)
		2516.49	0.016(5)
		2421.90	0.006(2)
		1946.20	0.014(4)
3140.90	2612.80(60)	2589.24	0.027(4)
		2519.49	0.014(5)
3137.90	2615.80(25)	2549.92	0.011(3)
3133.70	2620.00(19)	2554.12	0.015(3)
3130.20	2623.50(20)	2599.94	0.012(4)
		2530.19	0.014(3)
3127.60	2626.10(9)	2626.10	0.053(4)
3124.90	2628.80(45)	2605.24	0.009(4)
		2562.92	0.010(3)

Table 1. (cont.)

E_1	E_i	E_2	$i_{\gamma\gamma}$	E_1	E_i	E_2	$i_{\gamma\gamma}$
3121.50	2632.20(46)	2632.20	0.015(3)	3043.80	2709.90(20)	2709.90	0.018(4)
		2608.64	0.010(4)			2686.34	0.019(4)
		2566.32	0.013(3)			2522.00	0.009(3)
		2538.89	0.018(4)	3040.90	2712.80(20)	2712.80	0.028(5)
		2444.30	0.014(3)			2689.24	0.094(6)
		1902.20	0.016(4)			2646.92	0.025(3)
3114.90	2638.80(60)	2615.24	0.020(4)			2619.49	0.014(3)
3112.10	2641.60(24)	2641.60	0.016(3)			2524.90	0.018(3)
3108.30	2645.40(20)	2645.40	0.019(3)			2469.10	0.011(3)
		2579.52	0.020(3)	3036.90	2716.80(120)	1894.03	0.011(4)
		2552.09	0.048(5)	3035.50	2718.20(119)	2652.32	0.009(3)
		2457.50	0.008(3)			2624.89	0.024(4)
		1915.40	0.012(4)	3031.10	2722.60(30)	2656.72	0.012(3)
		1877.01	0.013(3)			2629.29	0.029(4)
3104.00	2649.70(82)	2626.14	0.024(4)			2534.70	0.007(3)
3102.00	2651.70(60)	2585.82	0.007(3)	3028.10	2725.60(26)	2537.70	0.011(3)
		2558.39	0.037(5)	3025.90	2727.80(40)	2727.80	0.015(4)
		2463.80	0.010(3)			2704.24	0.016(3)
3100.50	2653.20(20)	2629.64	0.041(5)			2634.49	0.008(3)
3099.40	2654.30(72)	2654.30	0.019(3)	3023.10	2730.60(33)	2730.60	0.019(4)
3099.00	2654.70(40)	2588.82	0.014(3)	3016.30	2737.40(50)	2737.40	0.044(5)
		2561.39	0.032(5)			2713.84	0.018(5)
		2466.80	0.015(3)			2671.52	0.017(3)
		1991.10	0.045(4)			2644.09	0.029(4)
3096.00	2657.70(29)	2657.70	0.012(3)	3013.30	2740.40(39)	2552.50	0.007(3)
3090.50	2663.20(63)	2663.20	0.015(3)	3001.90	2751.80(50)	2751.80	0.015(4)
		2639.64	0.012(3)			2658.49	0.055(5)
		2597.32	0.009(3)			2563.90	0.014(3)
		2569.89	0.010(3)	2997.50	2756.20(20)	2756.20	0.012(4)
		2475.30	0.007(3)			2690.32	0.017(3)
		1933.20	0.016(4)	2993.30	2760.40(20)	2760.40	0.034(5)
3086.20	2667.50(40)	2667.50	0.021(4)			2736.84	0.014(4)
		2643.94	0.011(3)	2988.60	2765.10(90)	2765.10	0.012(3)
		2574.19	0.008(3)			2741.54	0.011(4)
3082.90	2670.80(50)	2670.80	0.030(4)			2671.79	0.014(3)
		2647.24	0.011(3)			2591.40	0.002(1)
		2604.92	0.015(3)			2035.10	0.012(4)
3078.60	2675.10(45)	2651.54	0.032(4)	2983.40	2770.30(30)	2676.99	0.011(3)
		2581.79	0.024(4)			2582.40	0.008(3)
3074.10	2679.60(14)	2656.04	0.033(4)	2981.60	2772.10(45)	2706.22	0.009(3)
3071.30	2682.40(32)	2682.40	0.013(3)			2584.20	0.010(3)
		2658.84	0.022(4)			2042.10	0.011(4)
		2589.09	0.017(4)	2975.70	2778.00(17)	2590.10	0.017(3)
3068.30	2685.40(10)	1955.40	0.012(4)	2971.10	2782.60(30)	2689.29	0.008(3)
		1862.63	0.021(4)			1865.00	0.056(12)
		1767.80	0.050(10)	2968.70	2785.00(40)	2785.00	0.081(8)
3058.40	2695.30(30)	2629.42	0.009(3)			2761.44	0.011(4)
		2601.99	0.041(4)			2691.69	0.008(4)
		1965.30	0.015(4)			1867.40	0.079(13)
3056.30	2697.40(32)	2631.52	0.024(3)	2965.90	2787.80(43)	2787.80	0.015(5)
		2523.70	0.003(1)	2963.50	2790.20(17)	2602.30	0.018(3)
3050.50	2703.20(30)	2609.89	0.013(3)	2959.30	2794.40(40)	2770.84	0.038(5)
3047.00	2706.70(112)	2683.14	0.009(3)			2606.50	0.007(3)
		2518.80	0.021(3)			2550.70	0.012(3)
		2043.10	0.015(4)	2957.10	2796.60(60)	2796.60	0.018(4)

Table 1. (cont.)

E_1	E_i	E_2	$i_{\gamma\gamma}$
		2703.29	0.084(6)
		2028.21	0.012(3)
2954.70	2799.00(10)	2775.44	0.090(7)
2949.60	2804.10(50)	2780.54	0.021(4)
		2738.22	0.020(4)
		2710.79	0.034(4)
		2616.20	0.011(3)
		2035.71	0.010(3)
2941.30	2812.40(70)	2788.84	0.018(4)
		2624.50	0.009(3)
2938.50	2815.20(35)	2815.20	0.017(4)
		2627.30	0.017(3)
2932.30	2821.40(28)	2797.84	0.015(4)
2917.70	2836.00(30)	2812.44	0.018(4)
		2770.12	0.008(3)
		2742.69	0.017(3)
		2172.40	0.013(4)
2915.60	2838.10(70)	2838.10	0.008(3)
		2069.71	0.008(3)
2913.90	2839.80(20)	2651.90	0.014(3)
2896.90	2856.80(70)	2856.80	0.025(4)
		2790.92	0.009(4)
2887.10	2866.60(55)	2866.60	0.008(3)
		2678.70	0.008(3)
2884.80	2868.90(5)	2803.02	0.015(3)
		2775.59	0.012(4)
		2681.00	0.019(3)
		2205.30	0.015(4)
		2100.51	0.008(3)
2881.60	2872.10(65)	2872.10	0.012(3)
		2848.54	0.019(4)
		2806.22	0.008(3)
2878.90	2874.80(26)	2686.90	0.012(3)
2872.50	2881.20(60)	2857.64	0.036(5)
		2787.89	0.014(5)
		2693.30	0.017(3)
		2058.43	0.032(6)
		1963.60	0.049(12)
2871.70	2882.00(60)	2816.12	0.011(3)
		2788.69	0.011(5)
2861.50	2892.20(20)	2798.89	0.022(4)
		2704.30	0.012(3)
2851.60	2902.10(70)	2902.10	0.007(3)
		2878.54	0.010(4)
		2808.79	0.046(6)
		2238.50	0.012(4)
2843.60	2910.10(50)	2910.10	0.010(3)
		2886.54	0.014(4)
		2816.79	0.034(5)
		2722.20	0.014(4)
		2087.33	0.016(4)
2840.50	2913.20(99)	2889.64	0.020(4)
		2725.30	0.014(4)
2839.50	2914.20(20)	2848.32	0.014(3)
2832.00	2921.70(20)	2921.70	0.015(4)

E_1	E_i	E_2	$i_{\gamma\gamma}$
		2898.14	0.014(4)
		2855.82	0.015(3)
2825.30	2928.40(1)	2904.84	0.012(4)
		2862.52	0.007(3)
		2740.50	0.029(3)
2819.90	2933.80(20)	2933.80	0.033(4)
		2867.92	0.026(3)
2809.90	2943.80(124)	2943.80	0.038(5)
		2850.49	0.030(5)
		2755.90	0.017(3)
2808.80	2944.90(95)	2176.51	0.018(3)
2803.60	2950.10(25)	2762.20	0.068(4)
		2286.50	0.018(4)
2797.60	2956.10(17)	2768.20	0.019(3)
2789.30	2964.40(29)	2776.50	0.011(3)
2786.70	2967.00(24)	2303.40	0.019(4)
2776.30	2977.40(20)	2789.50	0.011(3)
2768.20	2985.50(20)	2985.50	0.013(4)
		2892.19	0.020(4)
		2797.60	0.018(3)
2763.00	2990.70(30)	2967.14	0.034(5)
		2897.39	0.034(5)
		2802.80	0.068(4)
		2327.10	0.016(4)
		2222.31	0.016(3)
2748.90	3004.80(70)	3004.80	0.007(4)
		2981.24	0.010(4)
		2938.92	0.043(4)
		2182.03	0.018(5)
		2087.20	0.033(12)
2743.30	3010.40(15)	2280.40	0.013(4)
		2092.80	0.036(12)
2720.40	3033.30(28)	2369.70	0.016(4)
2716.50	3037.20(20)	3037.20	0.030(4)
		3013.64	0.022(5)
		2849.30	0.008(3)
2706.10	3047.60(30)	3047.60	0.011(4)
		2130.00	0.035(10)
2700.70	3053.00(40)	3053.00	0.031(5)
		3029.44	0.022(4)
		2959.69	0.031(5)
		2389.40	0.018(4)
		2323.00	0.023(4)
2689.60	3064.10(23)	2241.33	0.022(5)
2684.70	3069.00(42)	2151.40	0.034(11)
2666.00	3087.70(20)	3064.14	0.035(4)
		2994.39	0.013(3)
2661.70	3092.00(33)	2428.40	0.014(4)
2658.80	3094.90(25)	2326.51	0.010(3)
		2272.13	0.052(7)
2653.80	3099.90(28)	2369.90	0.017(4)
2647.30	3106.40(39)	2376.40	0.012(4)
2629.10	3124.60(24)	2356.21	0.016(3)
2553.30	3200.40(18)	2282.80	0.075(12)
2512.10	3241.60(31)	2418.83	0.020(6)

Table 1. (cont.)

E_1	E_i	E_2	$i_{\gamma\gamma}$	E_1	E_i	E_2	$i_{\gamma\gamma}$
2504.20	3249.50(21)	2426.73	0.034(7)			2345.40	0.037(11)
2490.70	3263.00(50)	2440.23	0.017(5)	2476.80	3276.90(29)	2359.30	0.050(11)

Analysis of the experimental data requires transformation of the peak areas of the resolved cascades into absolute values (in % per decay). However, the direct solution of this problem, using, for example, the areas of peaks in the sum coincident spectrum, is practically impossible because of the uncontrollable conditions of the experiment. First of all, this is due to difficulties of determining the number of captures in the target with the error less than 10% and, especially, the absolute efficiency of registration of the cascade in the used geometry of the experiment [3]. This problem can be solved by the normalization of relative intensities to the absolute values $A_{\gamma\gamma}$ calculated for the most intensive cascades by the relation

$$A_{\gamma\gamma} = i_1 \times B_r \,, \tag{1}$$

where the absolute intensities i_1 of primary transitions are taken from other works, and the branching ratios B_r are determined in a standard way from the codes of coincidence accumulated in this experiment. The use of a maximum large ensemble of reference cascades (with the biggest B_r values) in such normalization allows one to minimize both statistical and systematical errors of the procedure and practically reduce them to existing errors of i_1.

Table 2. The energies E_1 and absolute intensities (% per decay) i_1 of the most intensive transitions used for normalization of the cascade intensities in the ^{185}W. $\sum i_{\gamma\gamma}$ *is the observed total intensity of cascades with corresponding primary transition.*

E_1, keV	i_i	$\sum i^*_{\gamma\gamma}$
5752.90(5)	2.13(6)	
5089.71(4)	3.74(9)	4.83(5)
4930.63(28)	1.76(2)	1.73(2)
4747.66(17)	4.05(4)	3.84(3)
4571.98(3)	6.07(10)	6.01(7)
4534.15(3)	4.21(7)	4.63(11)
4311.94(6)	2.14(6)	1.47(2)
4466.58(16)	1.07(11)	0.38(1)
4217.87(4)	2.34(6)	1.12(3)
4180.52(24)	0.46(6)	0.24(2)
4079.18(29)	0.60(9)	0.23(2)
4034.62(8)	1.09(5)	0.94(2)
Total	29.7(3)	27.6(2)

* Because of the lack of $i_{\gamma\gamma}$, the i_1 value is included in the sum.

We performed also experiments for the independent determination of the absolute intensities of γ-transitions for all 4 studied isotopes of W. For this purpose, the spectra of γ-rays following thermal neutron capture in targets enriched in ^{184}W and natural W were measured. From a comparison between the intensities of γ-transitions following thermal neutron capture in natural target and that after the radioactive decay of ^{187}W, the normalizing coefficient was determined to be equal 0.0415(22) for the relative intensities listed in Ref. [8]. Then, the areas of the peaks in the single spectrum for the target enriched in ^{184}W were corrected for the efficiency of the spectrometer and (if necessary) contribution of the background peaks. This permitted us to determine the absolute intensities of primary transitions i_1 which are used for the normalization of the total intensities of studied cascades in ^{185}W. The parameters of these cascades are listed in Table 2.

Table 3. The sum energies (keV) *of cascades E_c, the calculated $I_{\gamma\gamma}^{\mathrm{cal}}$ and experimental $I_{\gamma\gamma}^{\mathrm{exp}}$ intensities (% per decay) of the two-step cascades in* ^{185}W.

E_c, keV	E_f, keV	$J^\pi, K[Nn_z\Lambda]$	$I_{\gamma\gamma}^{exp}$	
5753.70	0	3/2- 3/2[512]	12.1(6)	6.6
5730.14	23	1/2- 1/2[510]	11.0(6)	6.5
5687.82	66	5/2- 3/2[512]	5.1(4)	3.2
5660.39	93	3/2- 1/2[510]	12.0(7)	6.6
5565.80	187	5/2- 1/2[510]	3.8(2)	2.3
5510.00	243	7/2- 7/2[503]	0.7(3)	0.01
5090.10	663	3/2- 7/2[503]+Q	3.0(6)	1.6
5023.70	729	3/2- 7/2[503]+Q	3.1(3)	1.4
4985.31	768	1/2-	1.5(1)	1.3
4930.93	823	3/2-	2.6(8)	1.2
4926.20	827	3/2-	1.7(1)	1.2
4836.10	917	(1/2-)	[3.3]	0.9
4685.60	1068	3/2-	[0.9]*	0.7
4652.00	1101	3/2- 1/2[521]	[1.2]*	0.6
4572.16	1181	1/2- 1/2[501]	[0.8]*	0.6
Total			62.8(17)	34.7

* Intensity was obtained from the ratio of the peak areas assuming an equal intensity of cascades to the levels with $J^\pi = 1/2^-, 3/2^-$ in ^{185,187}W.

These data are compared with the total intensities of all observed cascades with the primary transitions of the corresponding energy. Because of the lack of systematical errors in the determination of the cascade intensities, the ratio $R = \sum i_{\gamma\gamma}/i_1$ should decrease when E_1 decreases. Values of R larger than unity give some total uncertainties for both intensities. Besides, owing to the considerably different backgrounds in the spectra of cascade transitions and single γ-transitions, contribution of systematical error of i_1 in this uncertainty is larger than that of $i_{\gamma\gamma}$, at least for the smallest E_1.

The total absolute intensities $I_{\gamma\gamma} = \sum i_{\gamma\gamma}$ of cascades with a fixed sum energy (including those unresolved experimentally) obtained in this way at the detection threshold of quanta $E_\gamma > 520$ keV are listed in Table 3. Here energy interval of the cascade final levels E_f is limited by the conditions of the experiment – at the higher energies E_f, the ratio peak-to-background in the sum coincidence spectrum decreases. This does not allow one to get spectroscopic information on the cascades to the levels $E_f > 1$ MeV.

Table 3 contains also the data on spin J^π and structure $K[Nn_z\Lambda]$ of wave function of the cascade final levels obtained from the preliminary analysis of the results of investigations of the (d,p) and (d,t) reactions performed in Munich.

3.1. *Intensities of cascades to the final levels with $E_f > 1$ (*MeV)

It is seen from Fig. 1 that in the sum-coincidence spectrum, a large number of the two-step cascades to the final levels with energy $E_f > 1$ MeV for both ^{187}W and ^{185}W is resolved. Due to a very bad peak-to-background ratio in this region of excitations, detailed spectroscopic information (like that given in Table 1) cannot be obtained. But these cascades contain important information on the partial widths of their secondary transitions to the excited states of a complex nucleus. At present, there is no experimental information of this kind for the populated and de-populated levels of heavy nuclei above the excitation energy of 1-2 MeV.

The only possibility to get the general picture of this process is try to estimate the total yield of the two-step cascades to the levels with $E_f > 1$ MeV. This can be done by a comparison between the peak areas in the sum coincidence spectrum for all values of E_f and is listed in Table 3 as intensities of the cascades to the lowest levels. It should be taken into account that the peak areas of the two-step cascades to levels $E_f > 1$ MeV increase due to increase of the registration efficiency of cascades with a smaller energy and, on the other hand, decrease owing to registration of one of the transitions following the cascade. The latter transfers the event from the full energy peak into the continuous background. (The probability of simultaneous registration of three-step cascades in the full energy peak is about 100 times less than that for two-step cascades.) Direct estimation of both values from the experiment is difficult – a wide "noise" line and specific sign-variable structures [2] cause a considerable error in the determination of the mean efficiency for the registration of the low intensity cascade. Unknown uncertainty of real multiplicity of γ-quanta following de-population of level E_f by the cascades as well as the uncertainty of the necessary calculated data on the response function of the spectrometer for quantum with the energy $E_\gamma \leq 2$ MeV leads to some error in the calculation of the total registration probability of the third and following cascade transitions. Therefore, the estimation of the coefficients needed for the correction was done experimentally in this work.

The mean efficiency of registration of the cascades terminating at final levels below 2.2 MeV was determined by a simple linear extrapolation of this value for the cascades to the levels with $E_f < 1$ MeV.

The coefficient P_n of the decrease in the peak areas in the sum-coincidence spectrum caused by registration of the residual portion of energy of γ-quanta depopulating level E_f was determined from the change of the ratios of areas of the single-escape and annihilation peaks in the sum-coincidence spectrum to the intensity i_1 of γ-transition with $E_\gamma = B_n - E_f$. The i_1 values were determined for different peaks of the sum coincident spectrum in an independent experiment. For the ground state and some low-lying levels with $E_f \leq 300$ keV, we assigned $P_n = 1$ because low-lying γ-transitions depopulating them are absorbed by lead filter used in the experiment. Under this obvious assumption, it was found that the experimental value of P_n averaged over the interval $\Delta E_f = 0.5 - 1.0$ MeV varies within the limits 0.8 to 0.7 with a relative error not larger than 25% when increasing E_f. This error includes both error in the determination of P_n caused by the experimental conditions and variations of P_n related to fluctuations of the mean multiplicity of γ-quanta depopulating level E_f. Very close values of P_n were obtained for ^{187}W at $E_f < 1.9$ MeV, too. This can be considered as an additional confirmation for the reliability of determination of this parameter. It should be noted that the doublets (related to different isotopes or double-escape peaks in ^{185}W) result in a very strong fluctuation of the determined values of P_n. In such cases, the P_n value for a certain cascade was determined by the interpolation over the neighbouring peaks in the sum-coincidence spectrum.

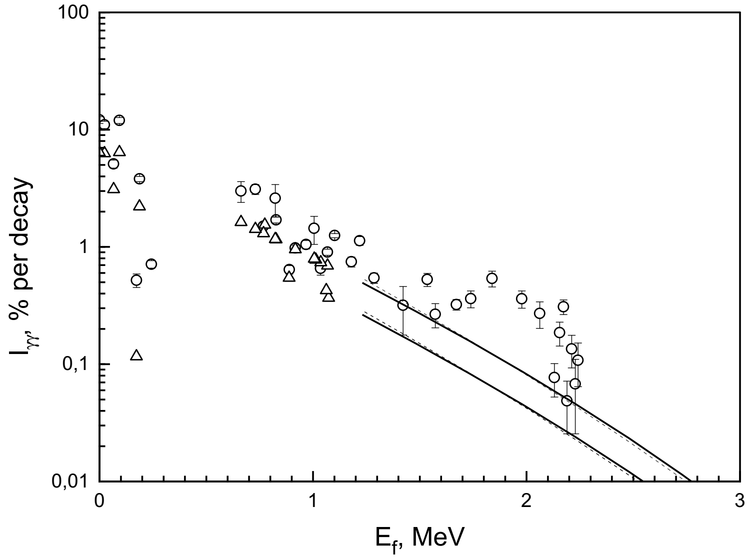

Fig. 3. Experimental estimation of the total intensity of the two-step cascades ^{185}W *up to the excitation energy of their final level* $E_f \approx 2.2$ MeV. *Lines and triangles represent results of the calculation within the models [10-12] for the final levels of cascades with* $J^\pi = 1/2^+, 3/2^+$ *(upper solid curve) and* $5/2^+$ *(lower solid curve), respectively. The dashed curves show the same for negative parity.*

It should be noted that the earlier modelling [9] of the process of registration of the third and other cascade quanta after the decay of the excited states of the even-even deformed nuclei gave close result, the areas of the peaks corresponding to the two-step cascades to the levels $E_f \simeq 1$ MeV decreases at most by the factor 1.3.

The intensity of the two-step cascades terminating at levels $E_f > 1$ MeV obtained in this way is shown in Fig. 3 in comparison with the theoretical values calculated according to the level density model [10] and models of radiative widths [11] and [12] for $E1$ and $M1$ transitions, respectively. The total experimental and calculated intensities of the cascades to levels $E_f < 2.2$ MeV are 70(4)% and 44%, respectively. So, this excludes the probability of correspondence between the model and the experimental values up to the excitation energy of about 2 MeV. This means that the sum of the experimental intensities of two-step cascades to the levels with the energy $E_f > 2.2$ MeV should be less than that predicted by the models mentioned above.

3.2. Background

Every spectrum – intensity distribution of cascades with a given sum energy contains the following components: (i) investigated cascade both in form of pairs of resolved peaks and their superposition – continuous distribution of low amplitude (cascade energy is completely deposited in detectors); (ii) "noise" line resulting from the registration of the part of the energy of quanta of cascades with the higher energy.

On the average, the contribution of the latter in the spectrum practically equals zero, but in some local sections of the spectrum, the distortions can be rather considerable. It should be noted that the main distortion is due to the cases of partial absorption of energy of one cascade transition in detector and complete absorption of the energy of another transition. Subtraction of this Compton background results in the appearance of characteristic symmetrical structures of variable sign in the spectrum of cascades with smaller sum energy. As it was shown in Ref. [2] that these structures manifest themselves when the full energy peaks of the high-energy cascades contain more than 1000 events. The use of a numerical algorithm for the improvement of the energy resolution [7] strengthens this effect. The shape of such structure is determined by the intensity of the corresponding individual cascade with higher energy, choice of concrete windows "effect+background" and "background" (Fig. 1) and is due to an inevitable discrepancy in the positions of these intervals. Of course, a similar effect exists also in the standard analysis of $\gamma - \gamma$ coincidences, but there it is well "masked".

Precise enough and complete correction of the corresponding distortions in the spectra, from which the data of Fig. 2 were obtained, can be calculated. This requires the data on the probability of simultaneous registration of quanta E_1 and E_2 in the full energy peaks for all possible most intensive cascades with the higher energy (included cascades in other isotopes and elements situated in the neutron beam). This procedure is absolutely necessary if HPGe detectors with the efficiency more than about 20% are used. Selection of parameters providing reproduction of the corresponding structures in a certain interval of a given spectrum (like that shown in Fig. 2) is not a problem: minimization of the sum of negative values of a spectrum allows one to provide very good numerical correction of the background under consideration. A part of the spectrum including the sign-variable structures before and after the simplest numerical corrections (under assumption that the form of such structure does not depend on the transition energies of cascades with larger total energy) is presented in Fig. 4.

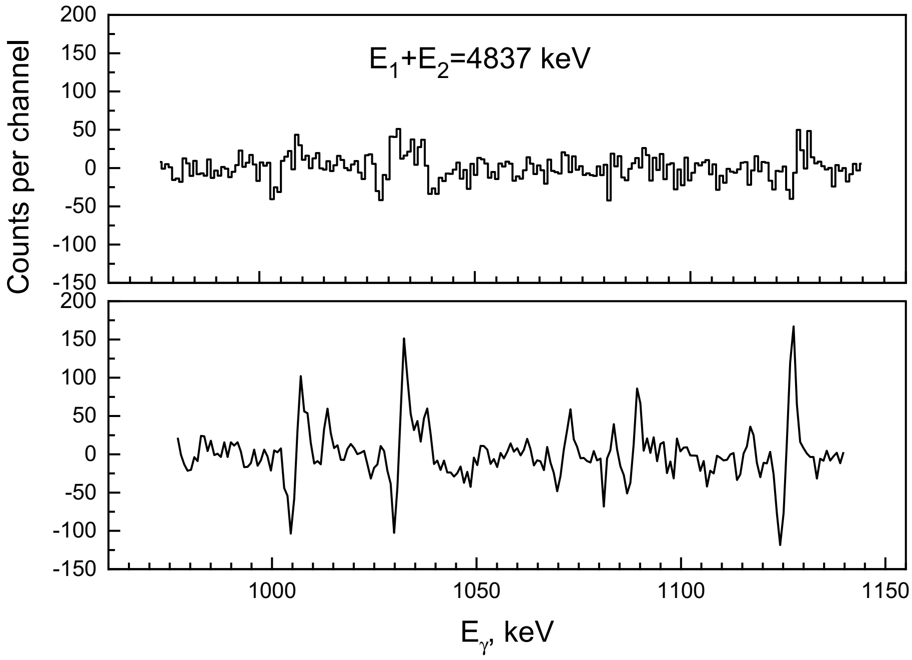

Fig. 4. An example of the numerical correction of the distortion of the form of the spectrum due to the presence of the "sign-variable" structures: the upper and lower plots show corrected and uncorrected spectra, respectively.

It is obvious that such a correction cannot be complete due to the random fluctuations of the background events in different sections of the sum coincidence spectrum.

3.3. The contribution of other tungsten isotopes

The main problem with the possible contribution of other tungsten isotopes in data of Table 1 is related with ^{187}W. In particular, this contribution appears in the sum-coincidence spectrum as overlapping of full energy peaks related with the cascade transitions in ^{185}W and ^{187}W. This overlapping affects 3 cascade intensity distributions measured in ^{185}W - 4685, 4652 and 4572 keV. The J_f^π value in these cases equals $1/2^-$ or $3/2^-$ for both isotopes. So, due to comparable numbers of neutron captures and approximate equality of the total cascade intensities, ^{187}W can give maximum contribution in the data of Table 1.

The overlapping of peaks corresponding to different isotopes requires a removal of well separated, intensive cascades belonging to the ^{187}W isotope from Table 1 and to correct the data in Table 3 for its contribution. The correction has a sense only if the cascades of ^{187}W determine a major part of the area of a given doublet in the sum coincidence spectrum. As a result, the experimentally resolved cascades of ^{187}W should be removed from all 3 spectra.

The removed cascades are attributed to ^{187}W if within the limits of three standard errors of determination of the intermediate level or γ-transition energy:

(a) intermediate levels with a corresponding energy are not observed in other spectra of ^{185}W; but

(b) the γ-transition with a close energy is observed in cascade primary transitions of ^{187}W.

This procedure is, however, more suitable for the determination of the level energies than for the determination of the decay modes of excited states. A number of cascade transitions observed with a relatively large mean error of determination of their energies ($\Delta E = 0.41$ keV) does not allow one to suggest a more reliable method to exclude cascades belonging to ^{187}W.

Moreover, presently available information [13] on thermal neutron radiative capture spectra of the ^{184}W and ^{186}W separated isotopes is considerably poorer than the data obtained in actual experiment and cannot be used in order to solve the problem under consideration.

The maximum number of primary transitions belonging to ^{187}W (but entered in Table 1) can be estimated from the frequency distribution of the difference between the energies of the primary transitions in corresponding spectroscopic data. Such frequency distribution shows that there is no visible (exceeding the limits of statistical fluctuations) admixture of the cascades of ^{187}W in the data of Table 1. The same situation is with the estimates of admixtures in Table 1 of the γ-transitions of ^{183}W and ^{184}W.

3.4. Comparison with a known decay scheme

The decay scheme was constructed by means of the algorithm described in Ref. [1]. The decay scheme of ^{185}W includes 781 two-step cascades proceeding via 282 intermediate levels with the excitation energy up to $\simeq 3.3$ MeV; 180 levels from them are depopulated by two or more secondary transitions. Hence, reality of these levels is confirmed with a high confidence. (The mean uncertainty in determination of the energy of the cascade quantum is 0.41 keV.) Quanta ordering for 102 cascades cannot be determined within algorithm [1] because the corresponding intermediate levels are depopulated only by one secondary transition. The neutron binding energy in ^{185}W equals 5754 keV, and energy of primary transition to the levels with $E_{ex} \geq 2$ MeV can be less than that of secondary transition. Linear extrapolation of the number of the excited levels depopulated by 2, 3 and 4 secondary transitions (59, 44, and 24 levels, respectively) provides probable estimation of the maximum number of such cascades — not more than 25–30. Most probably, this value is overestimated — the mean intensity $i_{\gamma\gamma}$ of the cascade to a given final level is approximately equal (2×10^{-4} per decay) for 1, 2 or 3 secondary transitions. But $i_{\gamma\gamma}$ considerably increases in the case of large multiplicity of secondary transitions. Therefore, one can assume that the number of the observed cascades with the multiplicity of secondary transitions 3, 2 and 1 is limited because often intensities of their primary transitions are less than the detection threshold L_c of the spectrometer. So, the energies listed in Table 1 of the excited states of ^{185}W correspond to reality at least at the 90% confidence level, if there is no unknown effect which gives false spectroscopic information. Consequently, the decay scheme of ^{185}W above $\simeq 1$ MeV established in our experiment seems to be more precise and reliable than that obtained earlier.

All levels of ^{185}W observed in this experiment with $J < 5/2$ are listed in Table 1. The known decay scheme of this nucleus includes only the part of possible levels from those listed in Table 1. This is due to its construction mainly on the basis of spectra of the primary γ-transitions following thermal neutron radiative capture. These spectra, however, were measured at real detection threshold $L_c \simeq 2 \times 10^{-3}$ events per decay. In our experiment are observed the states of ^{185}W populated by the cascades with the sum intensity exceeding $1 \div 3 \times 10^{-4}$ events per decay. The energy of intermediate levels for the majority of these cascades was determined according to Ref. [2] reliably enough, too.

4. *Possible regularity of the excitation spectrum*

According to the modern theoretical notions, the wave function structure of any excited states is determined by a co-existence and interaction between the fermion

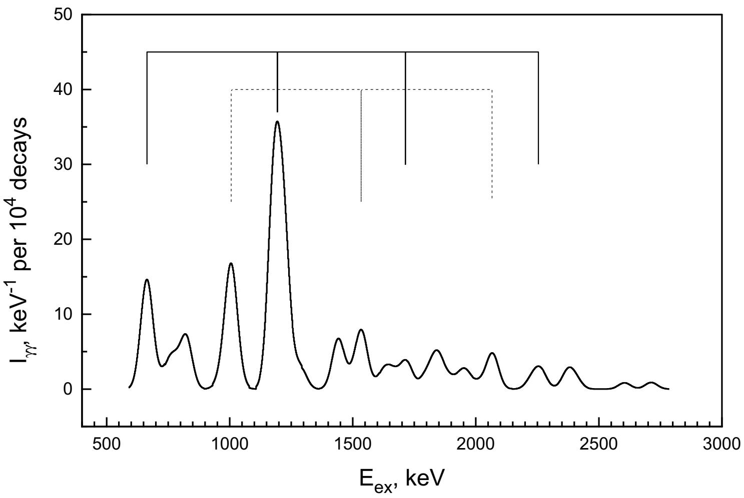

Fig. 5. The dependence of the "smoothed" intensities of resolved cascades listed in Table 1 on the excitation energy. Possible "bands" of practically harmonic excitations of the nucleus are marked. The parameter $\sigma = 25$ keV was used.

(quasi-particles) and boson (phonons) excitations. With the increase of excitation energy, a nucleus transits from practically mono-component excitations of the mentioned types to the mixed (quasi-particles $\otimes$ phonons) states with rather different [14] degree of their fragmentation. This process should be investigated in details, but there is no adequate experimental methods to study the structure of the wave functions above the excitation energy of 1–3 MeV in heavy nuclei like ^{185}W.

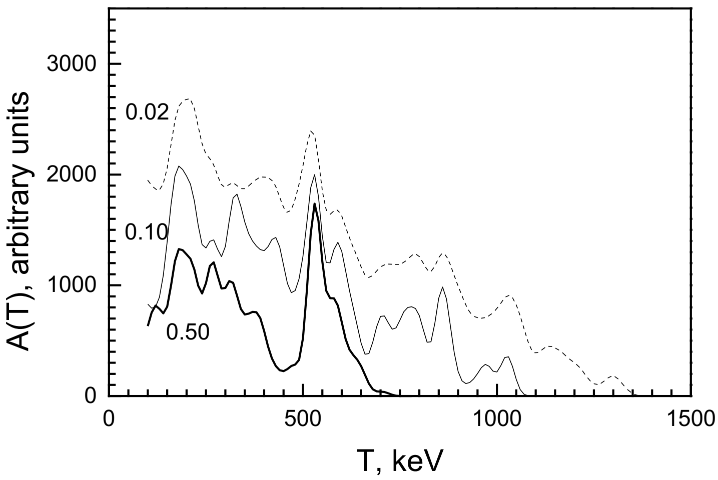

Fig. 6. The values of the functional $A(T)$ for three registration thresholds of most intense cascades. The value of the registration threshold (% per decay) is given in the figure.

Nevertheless, some information on the probable dominant components of wave functions of heavy deformed nuclei can be obtained. The authors of Ref. [15] suggested to search for the regularity in the excitation spectra of the intermediate levels of the most intensive cascades by means of the auto-correlation analysis of the smoothed distributions of the sum cascade intensities from Table 1. Intensities were smoothed by means of the Gaussian function: $F(E) = \sum_E I_{\gamma\gamma} \times exp(-0.5(\Delta E/\sigma)^2)$. The distribution of this type smoothed with the parameter $\sigma = 25$ keV is given in Fig. 5 and the values of the auto-correlation function

$$A(T) = \sum_E F(E) \times F(E+T) \times F(E+2T)\,, \tag{2}$$

for different selection thresholds of intensive cascades are shown in Fig. 6. As it was shown in Ref. [16] that such analysis cannot give a unique value of the equidistant period T even for the simulated spectra (for example, for 25 "bands" consisting from 4 levels with slightly distorted equidistant period) and provide estimation of the confidence level of the observed effect. In principle, both problems can be solved investigation of the two-step cascades due to different resonances of the same nucleus. But some grounds to state that the regularity really exists can be obtained from a comparison of the most probable equidistant periods in different nuclei. The set of the probable equidistant periods obtained so far (Fig. 7) allows an assumption that the T value is approximately proportional to the number of boson pairs in the unfilled nuclear shells. This allows one to consider the effect at the level of working hypothesis.

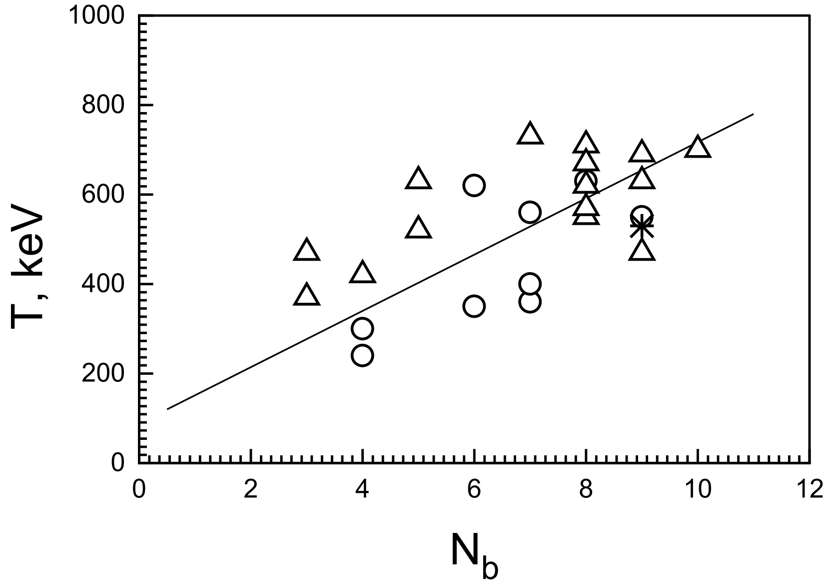

Fig. 7. The value of the equidistant period T for ^{185}W (asterisk), even-odd (triangles) and odd-odd (circles) nuclei as a function of the number of boson pairs, N_b in unfilled shells. The line represents possible dependence (drawn by eye).

The regularity in the excitation spectra testifies to the harmonic nuclear vibrations. Thus, one can assume that the structure of intermediate levels of the studied cascades contains considerable components of the rather weakly fragmented states like multi-quasi-particle excitations $\otimes$ phonon or several phonons. This provides a logical explanation for the considerable decrease in the observed level density as compared with the predictions of the non-interacting Fermi-gas model; the nuclear excitation energy concentrates on phonos, but quasi-particles up to $\simeq$ 2 MeV are excited weakly or very weakly due to an insufficiency of the energy for breaking of paired nucleons.

5. *Conclusion*

For the first time, the large and reliable scheme of the excited states and modes of their decay for the ^{185}W compound nucleus was obtained in the experiment up to the excitation energy $\simeq$ 3 MeV.

The results of a comparison between the experimental and calculated cascade intensities in this nucleus (like in the nuclei studied earlier) indicate a necessity to modify model notions of the properties of the excited states of the heavy nuclei. The obtained discrepancy between the experiment and calculation can be removed only with a more detailed accounting for a co-existence and interaction of fermion and boson excitations of nuclear matter by the nuclear models. Otherwise, achievement of a complete correspondence between the observed and calculated parameters of nuclear reactions, for instance, the neutron-induced reaction, is impossible. This concerns partially the total radiative widths of the neutron resonances and of the γ-spectrum.

Acknowledgements

This work was supported by GACR under contract No. 202/97/K038 and by RFBR Grant No. 99-02-17863.

References

[1] Yu. P. Popov, A. M. Sukhovoj, V. A. Khitrov and Yu. S. Yazvitsky, Izv. AN SSSR, Ser. Fiz. **48** (1984) 891.

[2] S. T. Boneva, E. V. Vasilieva and A. M. Sukhovoj, Izv. RAN. Ser. Fiz., **51** (1989) 2023.

[3] J. Honzátko et al., Nucl. Instr. and Meth. **A376** (1996) 434.

[4] S. J. Friesenhanh. E. Haadad, F.H. Frohner and W.M. Lopez, Nuclear Science and Engineering **26** (1966) 487.

[5] S. T. Boneva, E. V. Vasilieva, Yu. P. Popov, A. M. Sukhovoj and V. A. Khitrov, Sov. J. Part. Nucl. **22(2)** (1991) 232.

[6] S. T. Boneva et al., Part. Nucl. **22(6)** (1991) 698.

[7] A. M. Sukhovoj, V. A. Khitrov, Sov. J. Prib. Tekhn. Eksp. **5** (1984) 27.

[8] V. A. Bondarenko et al., Nucl. Phys. A **619** (1997) 1.

[9] I. Tomandl, Doctoral thesis, Řež (1999).

[10] W. Dilg, W. Schantl, H. Vonach and M. Uhl, Nucl. Phys. A **217** (1973) 269.

[11] P. Axel, Phys. Rev. **126** (1962) 683.

[12] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics*, Willey, New York (1952).

[13] http://www.nndc.bnl.gov/wallet/tnc/capgam.shtml.

[14] L. A. Malov and V. G. Soloviev, Yad. Fiz., **26(4)** (1977) 729.

[15] A. M. Sukhovoj and V. A. Khitrov, Izv. RAN, Ser. Fiz. **61(11)** (1997) 2068.

[16] E. V. Vasilieva et al., Bulletin of the Russian Academy of Science, Physics **57** (1993) 1582.

DVOJNE KASKADE U RASPADU SLOŽENE JEZGRE ^{185}W

Istraživali smo dvojne kaskade u reakciji ^{184}W(n_{th}, γ)^{185}W sudesnim mjerenjem $\gamma - \gamma$. To su prva mjerenja ukupnih intenziteta kaskada koje završavaju na energiji uzbude ≤ 2.2 MeV. Utvrdili smo shemu raspada ^{185}W sa 781 kaskada s enegijom uzbude oko 3.3 MeV. Kao i u ranijim istraživanjima, nalazimo da je spektar uzbude međustanja za najintenzivnije kaskade harmoničan.