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Levels in the N = 82 Nucleus ^{142}Nd*

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Decays of both ^{142}Pr and ^{142}Pm to levels in the 82 – neutron isotone ^{142}Nd were investigated with Ge(Li) detectors. The ^{142}Pm was not separated from the ^{142}Sm source and some ambiguity is present in the assignment of gamma-rays with energies up to 2.05 MeV. Spin and parity assignments were made for all levels. The resulting level scheme is compared with predictions of theoretical calculations.

Os níveis do ^{142}Nd foram estudados a partir da desintegração β^- do ^{142}Pr e β^+ do ^{142}Pm. Neste último caso, usou-se uma fonte de ^{142}Sm. Combinando-se resultados obtidos através da desintegração beta com os obtidos por meio de reações nucleares, spins e paridade de vários estados puderam ser fixados. Uma comparação com resultados teóricos, obtidos em um modelo de quase-partículas em interação é apresentada.

1. Introduction

In this paper we report some experimental results concerning the feeding of low energy levels of the ^{142}Nd nucleus ($Z = 60$, N = 82) by the beta decay of both ^{142}Pr and ^{142}Pm.

Nuclei with 82 neutrons are expected to present the same peculiar features as other single closed shell nuclei, e.g., $Z = 50$ or 82. In fact, the doubly – even N = 82 nuclei show all the signs of a single shell closure. It seems reasonable to suppose that they can be well described by a shell model in which the $Z = 50$ and N = 82 shells are inert while the remaining (Z – 50) protons are distributed over the next higher major shell. The latter are responsible for the main aspects of the lower energy levels (up to 3 MeV). The available single-particle orbits (s.p.o) above $Z = 50$ are the 1g 7/2 and 2d 5/2, almost degenerate in energy and, one MeV or so higher, the

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3s 1/2, 2d 3/2 and 1h 11/2 orbits. For a standard shell-model calculation there are too many protons distributed in these s.p.o. to make calculations practical and a better theoretical treatment is achieved through the BCS theory of superconductivity in a quasi-particle approach[1]. The available s.p.o. are the same we find for neutrons in the isotopes of tin, and this is to be reflected in the low energy level schemes of both groups of nuclei. However, it is worth noting that the accepted ordering of the s.p.o. is slightly different for protons and neutrons above Z or $N = 50$ and, more important than this, the protons outside the major closed shell are filling orbits already partially occupied by neutrons and the $T = 1$ proton-neutron interaction can hardly be neglected in a realistic calculation.

During the last few years, a great deal of new information about the excited states of ^{142}Nd has been accumulated in a large number of experiments: a) β^- decay[2] of ^{142}Pr, b) β^+ and EC decay[3,4] of ^{142}Pm, c) inelastic scattering of protons, deuterons[5] and alpha particles[6], d) (p, t) reaction[7,8] on ^{144}Nd, e) ^{141}Pr (He^3, d) reaction[8], f) ^{143}Nd (d, t) reaction[10] and g) proton decay of isobaric analogue resonances[10,11].

If results from the very restrictive beta decay selection rules are combined with data from angular distributions in particle scattering and single or double nuclear transfer reactions, some conclusions can be reached about the nuclear spins and parities of many low energy levels.

2. Experimental Techniques

The ^{142}Pr sources were obtained by irradiating the normally occuring praseodymium oxide for 4 hours in the 10^{13} n cm^{-2}s^{-1} flux from the reactor of the Instituto de Energia Atômica de São Paulo. Since the purity of our target material was not very high (99,0%), a great number of long lived undesired activities appeared and were identified by their characteristic gamma-rays energies and mean-lives.

The ^{142}Pm sources were prepared by irradiation of the samarium oxide (enriched in the ^{144}Sm isotope up to 97.8%) in the brernsstrahlung beam from the Centro Brasileiro de Pesquisas Físicas linear accelerator at an electron energy of 28 MeV. Irradiation times of about 3 hours were employed and a delay of 1 hour was imposed before the beginning of the measurements in order to allow the decay of the 9 min ^{143}Sm formed by (y, n) reaction. The ^{142}Sm, produced by (y, 2n) reaction, decays to ^{142}Pm with a half-life of 73 min. Since the half-life of ^{142}Pm is very short, no chemical separation was attempted and all the measurements were performed in presence of both activities.

Singles and coincidence gamma spectra were obtained with Ge(Li) detectors of 39 and 60 cm^3. Some low energy spectra were taken with a small (0.4 cm^3) high resolution detector. The high volume detectors were faced by a heavy lead-copper shield when the ^{142}Sm – ^{142}Pm sources were used in order to reduce the intensity of the annihilation peak. The resolving time for the coincidence unit and the source strength were chosen to give a true-to-chance ratio of about 10:1.

3. Results

The gamma-rays observed with a half-life of 73 min are given in Table I.

Arlt *et al.* (4)		Present work	
Energy (keV)	I_γ	Energy (keV)	I_γ
642 ± 1	19 f 3	641.6 ± 0.4	21.0 ± 2.0
679 ± 1	3.0 ± 0.6	677.1 ± 0.8	4.0 ± 0.5
849 ± 1	2.4 ± 0.5	848.3 ± 0.8	4.0 ± 0.5
954 ± 1	weak	953.0 ± 0.8	2.6 ± 0.5
–	–	1126.2 ± 0.8	0.8 ± 0.5
–	–	1155.8 ± 0.8	weak ($\lesssim$ 0.3)
1345 ± 2	4.0 ± 0.6	1344.8 ± 0.6	4.8 ± 0.5
1553 ± 2	1.0 + 0.2	1552.5 ± 0.8	0.9 ± 0.4
1576.0 ± 0.5	100	1575.8 ± 0.4	100
1830	weak	–	–
2385 ± 2	3.9 ± 0.6	2384.3 ± 0.8	4.0 ± 0.4
2584 ± 2	1.0 ± 0.3	2583.4 ± 0.8	1.0 ± 0.2
2848 ± 3	2.5 ± 0.5	2846.0 ± 0.8	2.5 ± 0.3
3046 ± 3	0.5 ± 0.15	3045.9 ± 0.8	0.70 ± 0.15
3131 ± 3	0.6 ± 0.2	3129.0 ± 1.0	0.50 ± 0.10
3361 ± 3	0.20 ± 0.05	3358.6 ± 1.5	0.25 ± 0.06

Table I - Energies (in keV) and relative intensities of the gamma-rays observed with a 73 min half-life.

The intensities are arbitrarily normalized to I_γ(1576 keV) = 100 and our results are compared with those of Ref. 4. A typical spectrum is given in Fig. 1. It corresponds to a single run with an accumulation time of 150 min. The intensity of the annihilation peak was estimated as 2120 ± 180. In the 73 min half-life activity no gamma-rays, except the characteristic X-rays, were observed with energies below 511 keV. Only the annihilation peak and the 641.6 keV gamma-rays were found in coincidence with the 1576 keV gamma-ray.

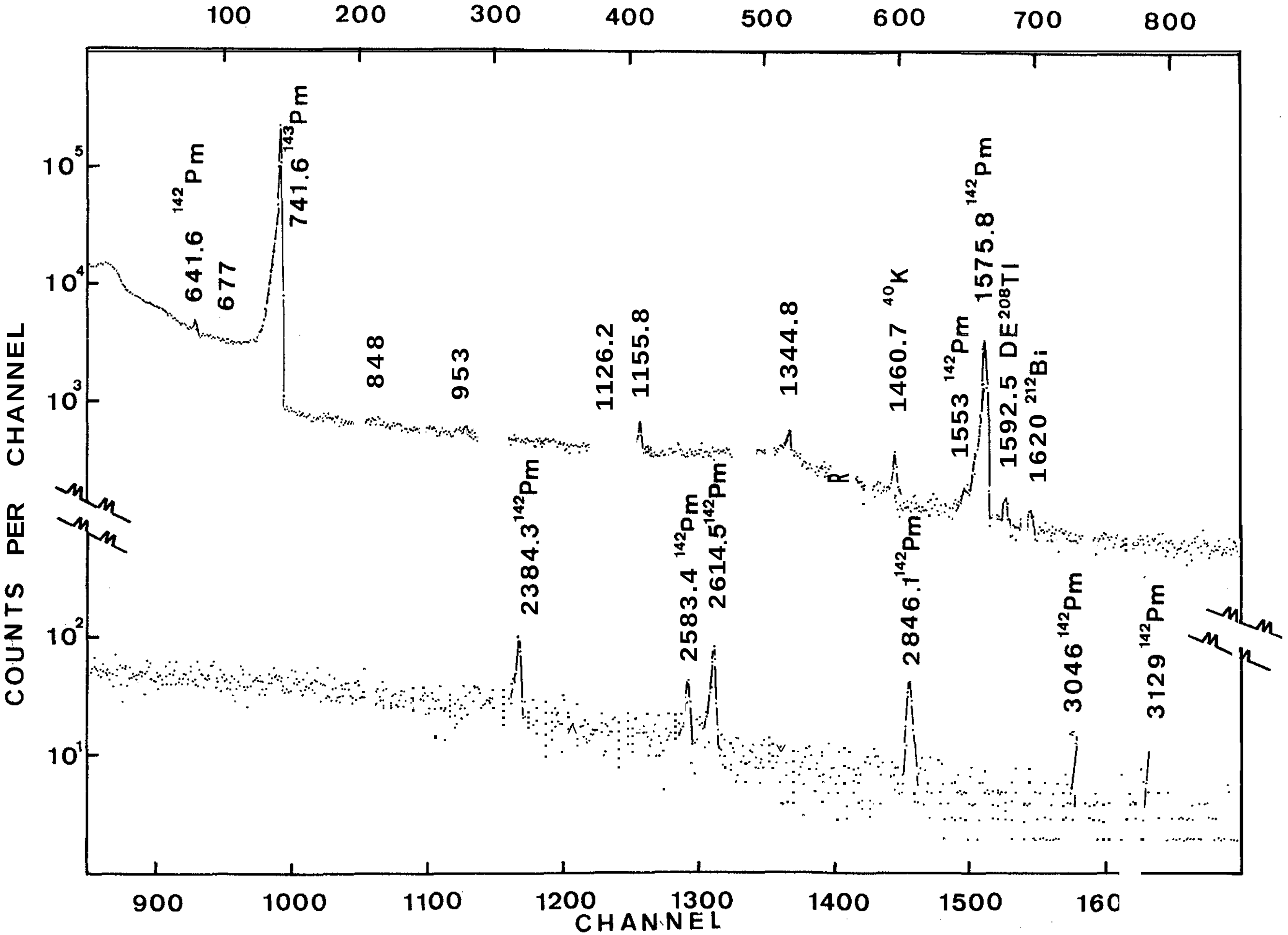

Fig. 1 - Gamma-ray spectrum taken with the 39 cm^3 Ge(Li) detector. Resolution FWHM is 3.0 keV at 1.33 Me

In a recent experiment, Raman[12] observed directly the decay of ^{142}Pm. The 41 sec activity was produced by ^{142}Nd (p, n) reaction. The gamma-rays of 677, 848, 953, 1126, 1156, 1345 and 1830 keV that appear in Table I were not observed. It is possible that at least some of these unobserved gamma-rays belong to the decay scheme of ^{142}Sm, i.e, they may correspond to the de-excitation of levels of ^{142}Pm. No other experimental data exist concerning the excited states of ^{142}Pm. On the other hand, weak gamma-rays with energies of 809.7 ± 1 keV, 1007.9 ± 0.8 keV and 1782 ± 2 keV were observed by him.

The decay of ^{142}Pr exhibits the 1575.8 keV gamma-ray (I, = 100) and a transition of 508.6 ± 0.4 keV with an intensity of 6.0 ± 0.4. These transitions are in coincidence with each other. The 509 keV transition is definitely not the same as the 525 ± 10 keV transition found[13] in the decay of the 16 μsec isomeric level of ^{142}Nd. This isomeric state is almost certainly a 6^+ level at 2209 ± 12 keV and it decays through a 4^+ level at 2100 keV. This last level was observed by the ^{141}Pr (He^3, d) reaction at 2.09 ± 4 0.02 MeV, about the same energy as the 3^- level fed by β decay. The angular distribution of the deuteron group indicates unambiguously a positive parity level, pointing to the existence of a doublet of opposite parity levels at this energy.

The ground state of ^{142}Pr is 2^- and $Q(\beta^-) = 2163$ keV[14]. The levels fed in its decay are the ground state[2], the 1575.8 keV 2^+ state and the 2084.4 keV 3^- state. These collective states are also observed in the inelastic scattering of deuterons and alpha particles. A 1970 keV 4^+ level was reported in Ref. 5 but it was not observed by any other author. A search for the 114 and 394 keV transitions from a possible cascade $3^- \rightarrow 4^+ \rightarrow 2^+$ gave no positive result. This level was not included by us in the level scheme that appears in Fig. 2.

The ground state of ^{142}Pm is probably 1^+ and its decay must be responsible for population of levels with $J^n = (0, 1, 2)^+$. Table II presents the energy levels of ^{142}Nd up to 3.3 MeV as determined by several experiments. Most probable energies and spin and parity assignments based on the overall experimental information are given in the last column.

A special comment must be made about the level at 2.92 MeV. This level is seen in the (p, t) reaction associated with an angular distribution that indicates a 0^+ state. The 1345 keV transition observed by Arlt *et al*[4]. and by us in the singles spectra could be associated with this level through the cascade $0^+ \xrightarrow{1345\,\text{keV}} 2^+ \xrightarrow{1576\,\text{keV}} 0^+$, a cascade of the same type as

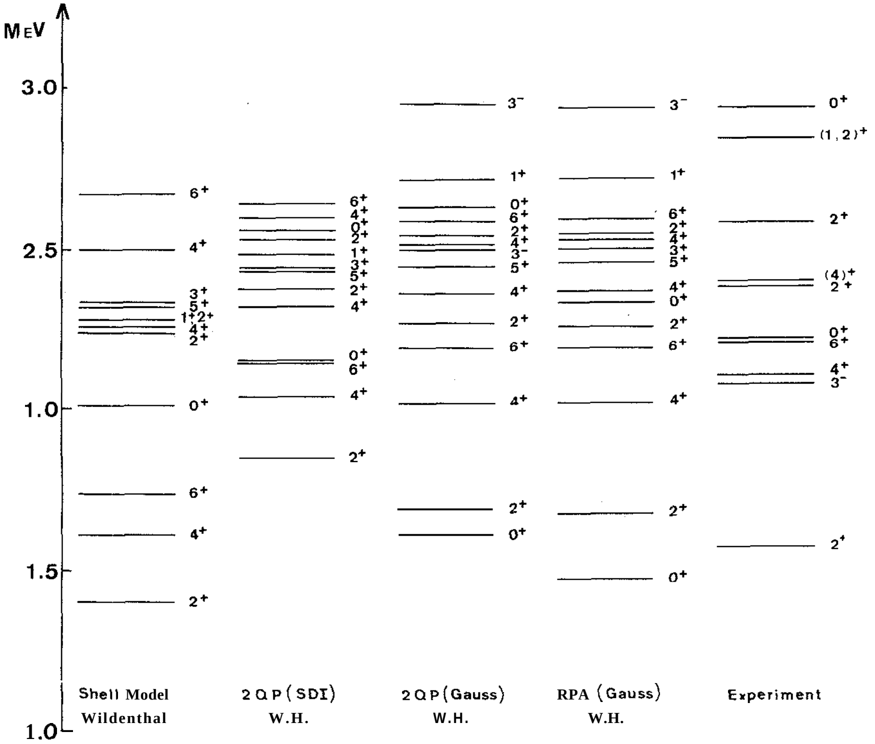

Fig. 2 - Comparison between experimental and theoretical level schemes. W. H.: Ref. 1. The experimental level scheme corresponds to the last column of Table II.

Present work		Decay of the isomeric level	(p, t) Ref. 7, 8		(d, d') Ref. 5		(α, E) Ref. 6		(He^3, d) Ref. 9		(d, t) Ret 10		(p, p') Ref 10, 11		Collation of results	
β^- decay	β^+ decay	Ref. 13	E	I	E	J^π	E	J^π	E	l	E	l	E	l	E	J^π
0.0	0.0	0.0	0.0	0	0.0	0^+	0.0	0^+	0.0	2	0.0	3	0.0		0.0	0^+
1.5758(4)	1.5758(4)	(1.576)			1.58(1)	2^+	1.572	2^+	1.57(2)		1.566(5)	1,3	1.57		1.5758	2^+
					1.97(2)										(1.97)	
2.0844(6)					2.09(1)	3^-	2.09	3^-					2.09		2.0844	3^-
		2.101(10)							2.09(2)	2					2.10	4^+
		2.209(10)							2.20(2)						2.21	6^+
	2.2174(6)		2.20	0	2.21(2)	0^+									2.2174	0^+
	2.3843(8)				2.39(2)				2.34(2)	2					2.3843	2^+
									2.40(2)	2					2.40	$(4)^+$
	2.5834(8)								2.55(2)	0					2.5834	2^+
	2.8460(8)								2.80(2)	0,2					2.8460	$(2)^+$
	2.8460(8)								2.80(2)	0,2					2.8460	$(2)^+$
	(2.9206(7))		2.91 2.94	0											2.92	0^+
	3.0459(8)								3.00(2)	(2)					3.0459	$(1,2)^+$
	3.1290(10)														3.129	$(1,2)^+$
									3.24(2)	5	3.263(5)	2	3.23		3.236	$^-$
											3.282(5)	0,2	3.280(5)	0,2	3.281	$(4)^-$
									3.30	0,2					3.30	$(2,3)^+$
											3.350	0,2	3.353(5)	0,2	3.352	$(3)^-$
	3.3586(15)								3.34(2)	0,2					3.359	$(1,2)^+$

Table II - Summary of spectroscopic information for ^{142}Nd as determined by the present work and nuclear reaction experiments. Energies are given in MeV.

that de-exciting the first 0^+ level at 2217 keV. However, this transition was neither observed by Raman[12] nor is in coincidence with the 1576 keV gamma-ray. The first argument is much stronger than the second since the poor statistics of our coincidence measurements place only an upper limit for the intensity of this line and this upper limit is barely one half of the intensity observed in the direct spectra. It seems that this level is not fed in the decay of ^{142}Pm and this fact points to a pairing vibration classification for this 0^+ state.

4. Conclusions

In Fig. 2 the experimental levels of Table II are compared with theoretical calculations. We selected levels up to 3.2 MeV since above this energy many particle-hole states of negative parity appear that are not described by current theoretical models. Wildenthal[15] has carried out a detailed shell-model calculation for the N = 82 isotones using a modified – surface δ interaction and the conventional j–j coupling. A severe truncation of the diagonalization space is imposed by the capabilities of the present computers. Calculations using quasi-particles techniques and the RPA approximation furnish a means of truncating the size of the shell model space. Such calculations were performed by Rho[16] and by Waroquier and Heyde[1] but again difficulties relating to the large size of matrices and cumbersome calculation of matrix elements impose practical restrictions and 4-qp admixtures are not considered. Waroquier and Heyde used the SDI and a gaussian force for the residual proton-proton interaction. The RPA approach was also employed. Except for the excited 0^+ states (which are too low) and for the 3^- state (which is too high), the calculated low energy levels are in good agreement with experimental results. From the 14 calculated levels up to 3 MeV, it seems that 10 levels are observed in the experiments. The missing states are $3^+)_1$, $5^+)_1$, $4^+)_3$ and $6^+)_2$. Since these levels (expected around 2.5 MeV) cannot be directly populated in the decay of both ^{142}Pr and ^{142}Pm it is not surprising that they were not observed in the present experiment. The 3^+ and 5^+ states are probably present in ^{138}Ba but in this nucleus the 0^+ excited states are missing.

In Figs. 3 and 4 a comparison is made between some selected levels in ^{142}Nd and in other well investigated N = 82 isotones[17–22]. Aside from the obvious correspondence between the first excited 2^+, 2^+, 6^+ states we observe some levels in the energy range 2 – 3 MeV that appear in a regular way in many isotones. Further experimental studies, nucleon transfer reaction data and decay studies, are needed to clarify some details of the level schemes of these nuclei.

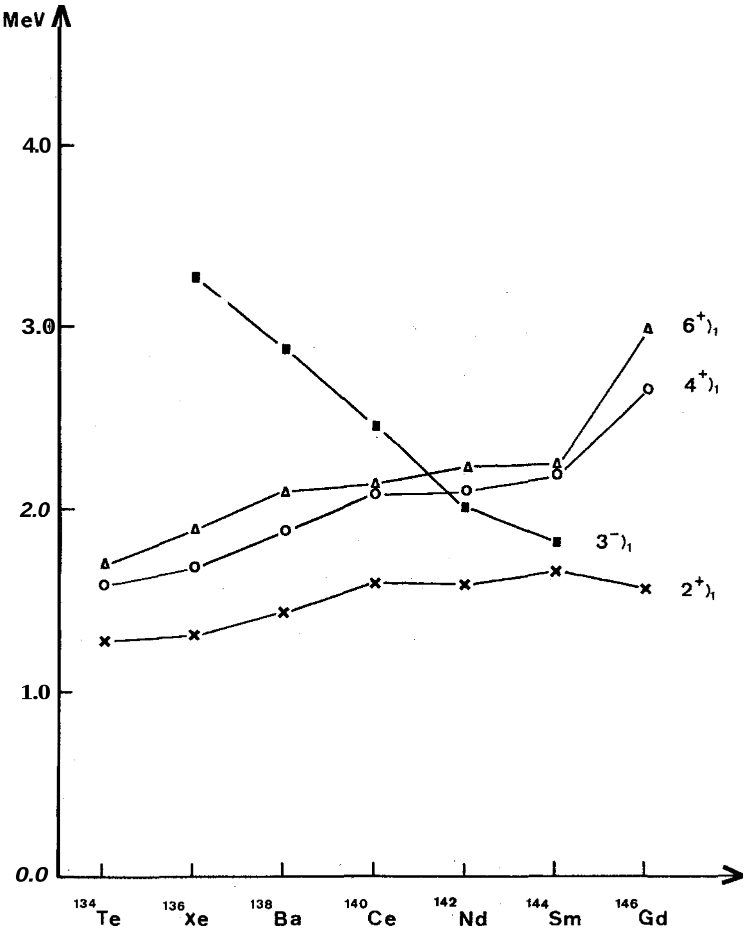

Fig. 3 - Comparison of the energy levels of the N = 82 isotones: *I*) $2^+)_1, 4^+)_1, 6^+)_1, 3^-)_1$ levels.

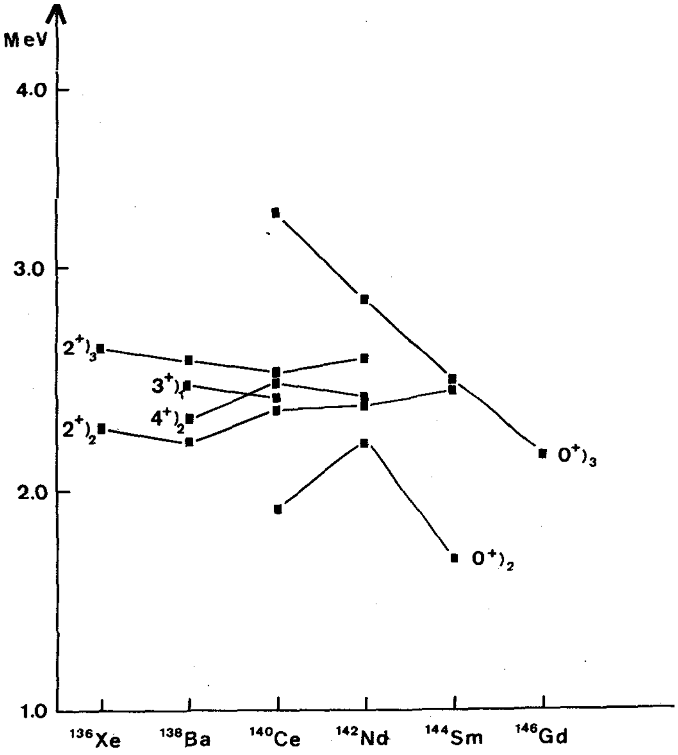

Fig. 4 - Comparison of the N = 82 isotones: II) $0^+)_2$, $0^+)_3$, $2^+)$, $2^+)$, $3^+)_1$ and $4^+)_2$ levels.

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