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STUDY OF ^{148}Sm LEVELS BY MEANS OF ^{147}Sm$(n_{res},\gamma)^{148}$Sm REACTION

L. Aldea, F. Bečvář, Huynh Thuong Hiep, S. Pospíšil,
S. A. Telezhnikov and V. G. Tishin

Joint Institute for Nuclear Research
Dubna, USSR

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ABSTRACT

The spectra of primary gamma-rays following neutron capture in ^{147}Sm corresponding to 23 isolated resonances have been used for the study of low-lying levels in ^{148}Sm and determination of capturing state spins. Of the 50 levels observed 11 have been detected for the first time. Substantially new information about the spins and parities has been obtained for 25 levels. A unique assignment is given for 10 levels. A detailed comparison of the results with those of previous works is done. An attempt is made to interpret the negative-parity levels in terms of the two-phonon quadrupole-octupole vibrations. The positive-parity levels are compared with those predicted by the asymmetric rotor model of Davydov and Filippov.

I. INTRODUCTION

The ^{148}Sm nucleus belongs to the so called transitional region of nuclei. While the deformed and spherical regions are successfully described by several theoretical models, the transitional region still suffers from a lack of a theory. The determination of ^{148}Sm levels and their spins and parities is important for the development and test of an adequate model.

The present knowledge of a system of ^{148}Sm levels is based on the information yielded by many different techniques.

The β^--decays od ^{148}Pm isomers were studied by Schwerdtfeger et al.[1], Reich et al.[2], Baba et al.[3], Avotina et al.[4], Wyly et al.[5] and Grigoriev et al.[6]. The β^+-decay of ^{148}Eu was measured by Schwerdtfeger et al.[1], Sugiama[7], Baba et al.[8], Cline[9], Harmatz and Handley[10] and Adam et al.[11]. The ^{148}Sm levels were extensively studied also via reactions with charged particles. The (d,p) and (p,p') reactions were studied by Kenefick and Sheline[12]. The (p,t) reaction was measured by Ishizaki et al.[13] and by Debenham and Hintz[14]. The (d,d') reaction was studied by Zeidman et al.[15] and Veje et al.[16]. The Coulomb excitation measurements were done by Seeman et al.[17] and Keddy et al.[18]. The (α,xn) reaction was used for the study of the ^{148}Sm levels by Adam et al.[19].

Other class of measurements included the (n,γ) reaction. The measurements with thermal neutrons were performed by Reddingius and Postma[20] and by Groshev et al.[21], while Gelletly and Kane[22] studied the (n,γ) reaction at the 3.4 eV resonance. Finally, Buss and Smither[23] measured the (n,γ) reaction by the average resonance capture method of Bollinger and Thomas[24].

Different techniques yielded rich information about the system of the ^{148}Sm levels. Nevertheless, the set of deduced levels below 3000 keV is still far from being complete. This is mainly due to appreciable non-uniformity in the population of the levels in most of above listed experiments.

An important contribution to the knowledge of the levels has been achieved by Buss and Smither[23]. They detected with exceptional efficiency the levels with $J^{\pi} = 2^+, 3^+, 4^+$ or 5^+ since their method allowed to reduce influence of violent Porter-Thomas[25] fluctuations on non-uniformity in population of the levels. Unfortunately, the experiment of Buss and Smither[23] led to two difficulties. First, the measurement has been performed with the natural Sm target which resulted in isotopic uncertainties of some deduced levels. Second, the average capture technique has not allowed to make a unique spin and parity assignment of the levels, since the averaging over two capturing state spins occurred.

The present work is an attempt to fill a still existing gap in the data. The two difficulties mentioned above are avoided, since the present experiment is based on the study of gamma-rays following the neutron capture in the <u>individual</u> resonances of the target <u>enriched</u> in ^{147}Sm.

Another aim of the present experiment was to measure relative partial radiative widths corresponding to the decay of many resonances to many final levels. These widths have been used for a test of statistical properties of highly excited states (resonances) in a frame of the extreme statistical model. The results of the statistical analysis will be presented in a separate paper.

II. EXPERIMENTAL ARRANGEMENT

The fast pulsed reactor IBR-30 of the Joint Institute for Nuclear Research has been used as a neutron source. The reactor worked in a booster mode of operation in conjunction with the 40 MeV linear electron accelerator LUE-40 used as an injector. The average power of the reactor was 6 kW at a repetition rate of neutron bursts 100 Hz. A full width at half maximum of the bursts was 3.5 μs.

The target was formed by 87.5 g of Sm_2O_3 enriched in ^{147}Sm to 96.4 %. For ^{147}Sm nuclei the target had a thickness of 1.99×10^{-3} $barn^{-1}$. The 50 m distance between the target and the source provided a time-of-flight (TOF) resolution power 70 ns/m. Capture gamma-rays were viewed by a 12.5 cm^3 coaxial Ge(Li) detector. A special stabilizing loop maintained the gain and the bias of the whole system including the preamplifier, main amplifier and the amplitude-to-digital converter. As a result, the resolution power for the spectra accumulated during a total period of measurement was 8.3 keV at the energy of 7 MeV.

Each event formed by 12 bits for the pulse height and 12 bits for TOF was stored in an intermediate memory serving as a derandomizer and then recorded on a magnetic tape with the density of 5 events/mm. In order to reduce recorded information, a digital discrimination was used. Only those events were recorded, which were falling into one of two narrow low-energy windows or above the gamma-ray energy of 3200 keV. The windows were adjusted so that the two corresponding portions of the gamma-ray spectrum involved the three strongest lines at 550.3, 611.4 and 630.0 keV.

After fifteen days of the data accumulation about 25 millions events have been recorded.

III. DATA PROCESSING

The accumulated information has been scanned on the BESM-4 computer. This yielded different TOF and gamma-ray spectra. One example is the TOF spectrum of the net 550.3 keV line shown in Fig. 1. This spectrum illustrates the achieved resolution in neutron energies. Square brackets in the bottom show main intervals selected for the scanning. The gamma-ray spectra for individual resonances are shown in Figs. 2a to 2e. The spectrum shown in Fig. 3 is formed by many resonances from 27.1 up to the energy of 170 eV and by unresolved neutron energy region from 170 to 900 eV. In the following we shall refer this spectrum as an averaged spectrum. In order to understand the structure of the background, a number of other auxiliary spectra have been obtained.

A decomposition of the gamma-ray spectra was done in two steps. The first one was a search for the positions of individual lines in the gamma-ray spectra. The second was based on the use of the code LINFIT written for the BESM-6 computer and provided an extraction of the areas of the individual lines in the individual resonances. In a fitting process the positions of all lines were fixed. The following features were included in the LINFIT.

(a) The response function of a single transition consisted of three Gaussian peaks, i. e. the double escape (DE), single escape (SE) and full energy (FE) peaks, with mutually dependent sizes. The relative size of the SE and FE peaks to the DE peak was determined by the detector used and was assumed to be energy-dependent. The size and the energy dependence of the FWHM was also preset. In fitting process the area of the DE peak was the only free parameter for the sizes of all three peaks.

(b) An accurate calibration in the gamma-ray energy based on a least-square fit of calibration data was included, which enabled to determine the positions of the SE and FE peaks relative to the DE peaks. Appart from the knowledge of the energies of some low-lying levels, the calibration routine itself used m_oc^2 differencies for some of the strongest triplets formed by the DE, SE and FE peaks. The calibration routine yielded also energies and associated errors for the observed transitions.

(c) The fit of the spectra could be done gradually in consecutive intervals. Each interval might contain the lines belonging to up to 50 transitions. The possibility of the fitting in large portions provided better determination of the smooth background under the peaks. The fit of the spectrum in the given interval made it possible to predict the sizes of some SE and DE peaks situated outside the interval. Before the fit of the next interval these peaks were subtracted from the experimental spectrum. The removal of the uninteresting peaks simplified the fit of next portions and minimized the number of fitted parameters.

The main advantage of the LINFIT was exclusion of the systematical error in the calculation of net DE peak areas, connected with the occurrence of SE and DE peaks.

In order to obtain relative intensities, the area of each DE peak in individual spectra was corrected for a Ge(Li) efficiency and divided by a quantity, which was a measure of the total capture rate for the given spectrum. This quantity is conventionally represented by the so called "capture area", which is the area under the gamma-ray spectrum above a threshold located usually around 2 to 4 MeV. However, such selection does not exclude influence of the background events. In addition, another distorsion comes from a high instantaneous counting rate on the resonances. As a consequence of the high rate, a certain fraction of the events belonging to peaks is due to pile-up thrown into the continuum, while the "capture area" remains unchanged. Hence, the "capture area" is not a good measure of the capture rate, since it does not reproduce the effect of pile-up for the DE peaks.

In the present experiment the quantity taken as a measure of the capture rate was the area of one of the low-energy lines. This removed the difficulties with the pile-up. The line used originated from the 611.4 keV transition connecting the 3^- level at 1161.7 keV and the 2^+ level at 550.3 keV. According to our cascade calculations based on von Egidy[26] method populations of the 1161.7 keV level are 20.62 and 19.82 % for the capturing state spins 3^- and 4^- respectively. It suggests, that the size of the 611.4 keV line can be taken as a measure of the capture rate even for the resonances of the different spin. The above described procedure yielded the relative intensities of the primary transitions to 50 final levels in ^{148}Sm for the spectra from 23 isolated resonances and for the averaged spectrum as well.

IV. EXPERIMENTAL RESULTS

A. Capturing state spins

Two different methods have been used for the determination of the spin of the resonances. The first one, more direct, was based on the analysis of high-energy parts of gamma-ray spectra from isolated resonances, while the second one was that of Poenitz[27] based on the properties of relative populations of low-lying levels.

Many previous studies of ^{148}Sm established firmly the 2^+ level at 550.3 keV. In addition, Buss and Smither[23] made a 2^+ or 5^+ assignment for two levels at 1453.0 and 1663.7 keV. Since the ^{147}Sm target has the spin and parity $I^\pi = 7/2^-$, s-wave neutron resonances excited in the present experiment can have a spin and parity $J^\pi = 3^-$ or 4^-. Intensities of E-2 and M-2 primary transitions are extremely weak, usually below a threshold of observation. Therefore, the transitions to the 2^+ and 5^+ states in ^{148}Sm could be observed exclusively in the spectra from the 3^- and 4^- resonances, respectively.

The spectrum of gamma-rays from the first resonance at 3.4 eV showed the presence of the primary transitions to all three above mentioned levels. The transitions are apparent in the spectrum in Fig. 2a as lines with the labels 1, 3 and 4. The occurrence of these transitions led to a 3^- assignment of the 3.4 eV resonance and to a 2^+ assignment for both levels at 1453.0 and 1663.7 keV. Thus, three levels with $J^\pi = 2^+$ were readily available. The observation of the transition to at least one of them in an arbitrary resonance indicated its 3^- assignment. By this way we were able to find an unambiguous 3^- assignment for 11 resonances.

The choice of the spin for the resonances was not independent of the determination of the spin and parity for <u>other</u> low-lying levels. In fact, the spin of the resonances and the spin and parity of low-lying levels were determined simultaneously. As it will be apparent from the detailed discussion later, the value 2^+ has been ascribed to other 7 levels in ^{148}Sm, while 3 levels have been determined as $J^{\pi} = 5^+$. Though all these 2^+ and 5^+ levels have been used for the determination of the capturing state spins, in some cases it was not possible to make a firm assignment. It was mainly due to a finite resolution power in TOF leading to imperfect separation of gamma-ray spectra of two or more closed resonances. Another limiting factor in determination of spins was the small number of available 5^+ levels. In addition, the 5^+ levels were situated in a region of high excitations, so that corresponding lines in primary gamma-ray spectra were superimposed on a high Compton background. The capability of the present experiment to detect transitions to the 5^+ levels was limited, particulary in cases of weak resonances.

The discussed method yielded results listed in the column "Primary gamma-rays" of Table I.

The second method used for the determination of the capturing state spins is based on the fact, that population of low-lying levels depends on the spin and parity of the capturing state. A quantity, which is usually available for the spin determination is a ratio of the intensities of the transitions resulting from a decay of two different low-lying levels. Sensitivity of this quantity to the capturing state spin depends on the spins and parities of the selected pair of final levels. A simple model of Poenitz[27] gives some prescriptions for the optimal selection of the spins and parities of the final levels.

Besides the systematical dependence on the capturing state spin, the above mentioned ratio is subjected to residual fluctuations originating from the Porter-Thomas[25] fluctuations of individual partial radiative widths. It is usually assumed that the residual fluctuations are very small, since an averaging over many levels has occurred. This should be true namely for those product nuclei with a large level density at excitation energies near a neutron threshold. So far, no calculations about the size of the residual fluctuations have been done.

A pair of the levels selected in the present study for the spin determination were the 3^- level at 1161.7 keV and the 4^+ level at 1180.3 keV. The ratios of the intensities of 611.4 and 630.0 keV lines resulting from the decay of these levels for individual resonances are plotted in Fig. 4. Data points are distributed in two groups corresponding to spin values 3^- and 4^- of s-wave capturing states. Though a sizeable scattering of the points around the two mean values occurs, in a number of cases it was still possible to determine the capturing state spin. The results are summarized in the colomn "Secondary gamma-rays" of Table I.

The capturing state spins determined by secondary gamma-rays are in reasonable agreement with spins based on the previous method. Nevertheless, the final selection of capturing state spins is made by a rather conservative way with strong preference for the results yielded by the analysis of primary gamma-rays.

A rough estimation has shown, that a not negligible part of the fluctuations of the points in Fig. 4 is caused by a finite resolution power in a neutron energy. This applies namely to the resonances located above 70 eV. Nevertheless, a correction for the resolution power results in only a small shift of the point for the 64.9 eV resonance, so that this point still falls into $J^{\pi} = 4^-$ group in spite of the fact, that the spectrum for that resonance contains quite strong transitions to the 2^+ levels at 550.3, 1453.0, 1663.7 and 2208.4 keV and no transitions to 5^+ levels. This discrepancy can be explained by either exceptionally large fluctuations of the relative populations or by occurrence of a doublet at 64.9 eV, consisting of two resonances with the different assignments 3^- and 4^-. In order to clarify this question, a search for a doublet structure of the 64.9 eV line has been done. The inspection of the latest available TOF spectra of Karzhavina and Popov[30] obtained with the resolution 6 ns/m has not revealed the doublet structure. Notwithstanding this fact, a possibility of the occurrence of the doublet with a separation up to 250 meV is not excluded. We note that another method of spin determination based on a measurement of gamma-ray multiplicities used by Karzhavina et al.[28] yielded a 4^- assignment for the 64.9 eV resonance.

Our data revealed a weak, previously unreported resonance at 5.29 eV. Since the resonance is observed in the TOF spectrum of the net 550.3 keV line, the resonance clearly belongs to the ^{147}Sm target nuclei. An estimation of a reduced neutron width $\Gamma_n^{(0)}$ of this resonance yielded a value of 1.8 μeV. This value is according to data of Karzhavina and Popov[30] 1.4×10^3 times lower than an average reduced neutron width $\langle \Gamma_n^{(0)} \rangle$. Taking into account Porter-

-Thomas fluctuations, a probability that a randomly selected resonance has $\Gamma_n^{(0)} \leq 1.8$ μeV is 2.1 %. Since this probability is small, the possibility of p-wave character of this resonance was tested. An estimation of the p-wave reduced neutron width led to a value $\Gamma_n^{(1)} = 148$ meV. According to the available information[31] about the p-wave strength function S_1, the value of $\Gamma_n^{(1)}$ would be 90 times higher than an average value $\langle \Gamma_n^{(1)} \rangle$. This excludes the p-wave assignment of the 5.29 eV resonance, since the value of $\Gamma_n^{(1)}$ is too large to be consistent with the Porter-Thomas fluctuations. This conclusion is true even if we admit, that the value of S_1 is in error represented by a factor of 5. As the s-wave assignment of the 5.29 eV resonance was reliably established, the method of relative populations could be used and yielded a $J^{\pi} = 4^-$ assignment for this resonance.

B. Levels of ^{148}Sm and their spins and parities

The present study of ^{148}Sm levels was based on an analysis of both, the gamma-ray spectra from isolated resonances and the averaged spectrum.

Averaged reduced intensities, i. e. transition intensities extracted from the averaged spectrum divided by E_{γ}^5 are shown in Fig. 5. Irrespective of considerable fluctuations, the average reduced intensities do not show a systematical dependence on the gamma-ray energy. This supports the similar conclusions of Bollinger and Thomas[24] about E-1 transitions, explained by the strong role of the giant dipole resonance in the mechanism of the (n,γ) reaction.

Simple considerations show, that the averaged reduced intensities should be bunched in two groups according to a spin of final levels. We assume, that the number of resonances with a given spin J which are included in our region of averaging is strictly proportional to the density $\rho(J)$ of resonant levels. Further, for a fixed final level we assume the proportionality

$$\langle \Gamma_{\lambda\gamma f} \rangle_{\lambda(J)} \sim \rho(J)^{-1}, \qquad (1)$$

where $\Gamma_{\lambda\gamma f}$ is the partial radiative width for the resonance λ and the final level f, and where the averaging is done over the resonances with the spin J. This proportionality is indirectly confirmed by the well-known fact, that total radiation widths do not show a dependence on J.

It follows from these two assumptions, that the group of the averaged reduced intensities of the E-1 transitions to 3^+ or 4^+ levels should be by a factor of 2 more intensive than the group of the transitions to 2^+ or 5^+ levels.

In accordance with the statistical model, the partial radiative widths $\Gamma_{\lambda\gamma f}$ for a fixed level f are distributed independently according to the Porter-Thomas[25] distribution, i. e. chi-squared distribution with one degree of freedom. A distribution of correctly averaged reduced intensities of each group can be then described by a chi-squared distribution with ν degrees of freedom, where ν is equal to the number of the included resonances giving the transition to the state f.

The averaged spectrum was formed by contributions of individual resonances with non-equal weights. In this case, the description of the fluctuations of the averaged intensities by the chi-squared distribution is not strictly valid. However, the chi-squared distribution with some effective value of ν can be used as a satisfactory approximation. Taking into consideration the capture rates of individual resonances, the effective value of ν has been calculated. It has been supposed that the contributions of the individual resonances to an unresolved part of the TOF spectrum from 170 to 900 eV (see Fig. 1) fluctuate like reduced neutron widths $\Gamma_{\lambda n}^{(0)}$ do, i. e. according to the Porter-Thomas distribution.

The effective value of ν obtained for the 3^+, 4^+ group was equal to 35. The analogical value of ν for the 2^+, 5^+ group depends on a ratio of the resonance densities $\rho(3^-)/\rho(4^-)$ and also on the ratio of the number of 2^+ levels to that of 5^+ levels. The value of 17.5 was used for the 2^+, 5^+ group as a reasonable approximation.

The distribution of the reduced averaged intensities of presumably E-1 transitions is shown in Fig. 6. The chi-squared distributions approximating the experimental data are also shown. The accordance between the histogram and the theoretical distributions is satisfactory.

Both groups are relatively broad. Nevertheless, for a number of cases it is still possible to distinguish $J^\pi = 2^+$ or 5^+ from $J^\pi = 3^+$ or 4^+.

Using the discussed chi-squared distributions, we have found that the averaged intensities of the 3^+, 4^+ group in the units used in Figs. 5 and 6 fall with 99.8 % probability within the interval from 0.43 to 1.82. An expectation value of the intensity for the 3^+, 4^+ group in the same units is equal to 1.00. The analogical interval for the 2^+, 5^+ group ranges from 0.14 to 1.17. For ^{148}Sm a ratio of the averaged reduced intensity of M-1 to that of E-1 is known. Buss and Smither[23] found it to be equal to 0.10. Using this value it has been estimated that M-1 averaged reduced intensities fall with 99.9 % probability below 0.18 units used in the above cases.

The knowledge of the limits for the values of the averaged intensities of the different groups allowed to draw conclusions about the spin and parity assignments of the final levels. The results are summarized in the column "Average" of Table II and they are determined with confidence higher than 99.9 %.

Other part of information was extracted from an analysis of the gamma-ray spectra of individual resonances. Limitations on the spin of the final levels which followed had been determined from the knowledge of the spin for the individual resonances assuming only an E-1 and M-1 character of the primary gamma-rays. A role of the E-2 and, in particular, M-2 transitions or their admixtures was neglected. This was justified by the estimation made by Buss and Smither [23], who found that the E-2 primary transitions in ^{148}Sm are at average 25 times weaker than the E-1 transitions. It is believed that the M-2 transitions are weaker than those of E-2.

Notwithstanding the fact, that broad Porter-Thomas fluctuations made it difficult to distinguish E-1 character from M-1 character in one resonance, in some cases it was still possible. These were the cases of E-1 transitions for which the reduced intensity exceeded at least 1.20 times the average reduced E-1 intensity. A confidence level for such determination of the E-1 character is higher than 99.9 %.

For a few levels it was possible to make a $J^{\pi} = 2^{\pm}, 3^{-}, 4^{-}$ or 5^{-} assignment on the basis of the absence of the corresponding transitions in the spectra from all 4^{-} resonances. For this purpose a proper test of statistical significance of this absence has been used.

The results of the spin and parity assignment based on the individual gamma-ray spectra from resonances are listed in the column "Resonance" of Table II. Table II lists also the important results of previous studies and the final conclusions.

In the following we present the detailed discussion of the results concerning more than a half of the levels detected by the present experiment.

C. Discussion of individual levels

Level at 1453.0 keV. The 6687.6 keV transition observed in the 3^{-} resonances leads to the 1453.0 keV level. The intensity of the transition averaged over 10 resonances with $J^{\pi} = 4^{-}$ corrected for the E_{γ}^{5} dependence is at least 6.2 times lower than an analogical value deduced from the E-1 transitions observed in the 4^{-} resonances. This rules out the values 3^{+}, 4^{+} and 5^{+} for the 1453.0 keV level. An intensity of the 6687.6 keV transition in the averaged spectrum restricts J^{π} to values of 2^{+} or 5^{+}.

Our data lead to an unambiguous 2^{+} assignment of the 1453.0 keV level within the confidence limit higher than 99.9 %.

An intensity of the 6688.0 keV line in the average spectrum of Buss and Smither[23] led to a 2^+ or 5^+ assignment of the level reported at 1453.6 keV.

In their Coulomb excitation study Keddy et al.[18] found the 1455 keV level and assigned $J^\pi = 2^+$ as the most probable value. Debenham and Hintz[14] studied the (p,t) reaction on the ^{150}Sm target and deduced some spins and parities of ^{148}Sm. They observed a direct population of their 1458 keV level and concluded that this can support the natural-parity 2^+ assignment of the 1458 keV level.

None of the β-decay works of Harmatz and Handley[10], Cline[9], Adam et al.[11] and Grigoriev et al.[6] reported the 1453.0 keV level. However, in a list of conversion electron lines presented in Ref. 10 there are included those corresponding to 1454.3 and 903.8 keV transitions, which were not placed in the decay scheme of ^{148}Sm. These transitions can originate from a decay of the 1453.0 keV level to G.S. and first excited 2^+ level at 550.3 keV. Analogically, the spectrum of gamma-rays in Ref. 9 contains lines with the energies 1454.3 and 903.9 keV.

Buss and Smither[23] subjected the data in Refs. 9, 10 to an additional analysis and found K conversion coefficient 3.9×10^{-3} for the 903.8 keV transition. The value which they obtained would correspond to M-1 multipolatity. However, because of the collective character of low-lying positive-parity levels one should expect E-2 multipolarity as the dominant one. Buss and Smither[23] explained the large conversion coefficient by a strong admixture of an E-0 component. Berzin et al.[34] have observed analogical strong E-0 admixtures for a number of transitions in the neighbour ^{150}Sm nucleus. Since the spin of the 550.3 keV level is well established to be 2^+, the possibility of the occurrence of the strong E-0 component led the authors in Ref. 23 to a conclusion that the most probable assignment of their 1453.6 keV level is 2^+.

In their study of thermal neutron capture in ^{147}Sm Groshev et al.[21] observed the 6686 keV transition corresponding to the 1455.5 keV level. The authors in Ref. 21 excluded a 5^+ assignment since they assumed a pure 3^- assignment for the thermal capturing state. However, the 6686 keV transition is very weak 0.01 % and, hence, it can be caused by a small cross-section contribution of the 4^- resonances and 4^- bound states into the thermal energies. As the contribution of the 4^- bound states is not enough known for the ^{147}Sm target, the conclusion of the authors in Ref. 21 must be treated with caution.

Up to now, the only direct conclusion about the spin and parity assignment $J^\pi = 2^+$ was done by Gelletly and Kane[22], who observed a weak 6688.0 keV transition from the 3^- resonance at 3.4 eV to their deduced 1453.6 keV level. However, as it will be shown below, the 3.4 eV spectrum in Ref. 22 yielded two lines which are not reproduced by our measurement an are probably spurious. In particular, one of these was reported in Ref. 22 even more intensive than the decisive 6688.0 keV line. This demonstrates ad hoc the importance of the independent determination of J^π for the discussed level.

The 2^+ assignment of the 1453.0 keV level is now firmly established by our data.

Level at 1594.0 keV. Harmatz and Handley[10], Cline[9], Adam *et al.*[11] and Grigoriev *et al.*[5] ascribed $J^{\pi} = 5^{-}$ to this level. An angular correlation of gamma-gamma cascades and K-electron conversion coefficient of the 414 keV transition according to Refs. 1, 7 led to a 3^{-} or 5^{-} assignment. The measurement of the (d,d') reaction by Veje *et al.*[16] gave a 5^{-} assignment. The exclusion of the 3^{-} assignment in Refs. 9, 10 is based on the existence of the transitions connecting the 1594.0 keV level with three $J^{\pi} = 6^{+}$ levels.

Groshev *et al.*[21] observed a very weak 6548 keV transition and proposed a 1593.5 keV level, however, they made no assignment.

Buss and Smither[23] reported a 1595.0 keV level and proposed a $3^{-}(4^{-})$ assignment as the best compromise between their data and the data of works. The only argument in favour of such conclusions was observation of a 1043.9 keV transition in the spectrum of Cline[9]. This transition can join his proposed 1594.1 keV level with the first excited level at 550.3 keV.

In our measurement the 1594.0 keV level is deduced from observation of the 6546.6 keV transition. The intensity of the transition in the averaged spectrum corresponds clearly to the group of negative-parity levels. The transition is observed in the 4^{-} resonances, which restricts the assignment of the 1594.0 keV level to values 3^{-}, 4^{-} or 5^{-}. However, the fact that we have not observed any trace of the 6546.6 keV transition in the 3^{-} resonances speaks against the $3^{-}(4^{-})$ assignment proposed by Buss and Smither[23] and supports the assignment 5^{-} made in Refs. 3, 6, 8, 9, 10, 11, 16.

In order to clarify the question of the assignment of the

1594.0 keV level, we subjected the conflicting data in Ref. 23 to an additional analysis.

The conclusion about the $3^-(4^-)$ assignment in Ref. 23 is based on two assumptions. First, the ratio of the averaged reduced intensity of E-1 to that of M-1 transition is independent of gamma-ray energy for the same spin of final levels and, second, this ratio is well determined by the intensities of reliably established E-1 and M-1 transitions to the levels with known spin.

There is very limited information about the properties of high-energy M-1 transitions. Emery and Shapiro[33] predicted a resonance character of the M-1 intensities for the deformed heavy nuclei with the maximum near 7 MeV. Data of Bollinger and Thomas[24] in case of the weakly deformed ^{106}Pd nucleus, that the dependence of the M-1 intensities on the gamma-ray energy has a giant-resonance-like shape, similar to that predicted in Ref. 33. This suggests that E-1 and M-1 photon strength functions can have quite different shapes and, hence, the above defined ratio can be energy-dependent.

Besides the M-1 transition to the 1595.0 keV Buss and Smither [23] observed with satisfactory accuracy only two other M-1 transitions to levels at 1162.2 and 2338.6 keV with the assignments 3^- and $2^\pm$, $3^-(4^-, 5^\pm)$, respectively. Relative errors in intensities of these two transitions are 15 and 30 %, respectively. Since the number of available M-1 intensities is small, residual Porter-Thomas fluctuations together with the experimental errors can cause a sizable error in the determination of the E-1 to M-1 transition intensity ratio.

A higher number of the M-1 transitions is known for the neighbour ^{150}Sm nucleus. The above mentioned ratio extracted from the data in Ref. 23 is equal to 8.6 and much better determined than in the case of ^{148}Sm. Using this value of the ratio for ^{148}Sm the intensities of the M-1 transitions to 3^- or 4^- levels are expected to be 8.6 times weaker than the intensities of the E-1 transitions to 3^+ or 4^+ levels. The averaged intensities of the M-1 transitions to the 2^- or 5^- levels are expected to be weaker by the factor of 17.2.

The intensity of the M-1 transition to the 1595.0 keV level in the averaged spectrum of Buss and Smither[23] is 11.5 ± 2.3 times weaker than the intensity of the E-1 transition to a 3^+ or 4^+ level at the equivalent excitation.

By comparison of the last value with two values 8.6 and 17.2 corresponding to two alternatives of the assignment, i. e. 3^- or 4^- and 2^- or 5^-, respectively, we can demonstrate that the 5^- assignment of the 1594.0 keV level is not in strong disagreement with the data in Ref. 23.

Level at 1663.7 keV. This level is deduced from the observation of a strong 6476.9 keV transition in a number of 3^- resonances, which restricts the assignment of the level to values 2^+, 3^+ or 4^+. Estimation of the ratio of an average transition intensity in 10 resonances with $J^\pi = 4^-$ to the average intensity expected for $J^\pi = 3^+$, 4^+ or 5^+ final levels is equal to 0.087 ± 0.073. This value rules out the 3^+, 4^+ or 5^+ assignment within the 99.99 % confidence limit. Our data lead to the 2^+ assignment of the 1663.7 keV level.

Buss and Smither[23] reported a 2^+ or 5^+ assignment for the level at 1663.4 keV. Results of Groshev <u>et al.</u>[21] and Gelletly and Kane[22] in a combination with the assignment reported in Ref. 23 led in both cases to the 2^+ assignment. A tentative 2^+ assignment for the discussed level was proposed in (d,d') work by Veje <u>et al.</u>[16] and in the (p,t) work by Debenham and Hintz[14].

<u>Level at 1903.0 keV</u>. This level is deduced from the observation of the strong 6237.6 keV transition in a number of resonances of both spin values 3^- and 4^-. The 1903.0 keV level with the 3^+ or 4^+ assignment is firmly established.

Buss and Smither[23] observed a 6238.7 keV primary transition, however, they ascribed it ambiguously to either ^{148}Sm or ^{150}Sm. For the case of ^{148}Sm they deduced a 1902.9 keV level with a 3^+ or 4^+ assignment.

There are no other papers reporting this level.

<u>Level at 1971.9 keV</u>. The 6168.9 keV transition observed in our spectra leads to a level in ^{148}Sm at 1971.9 keV. This transition is observed in a number of 3^- resonances with an intensity inconsistent with the M-1 character. The upper limit of the average intensity of the transition in the 4^- resonances is 6.3 times lower than the value expected for the 3^+, 4^+ and 5^+ final levels. This excludes the assignments 3^+, 4^+ and 5^+ for the 1971.9 keV level within the confidence limit 99.89 %. In addition, the intensity of 6168.9 keV transition in the spectrum averaged over neutron energies from 25 to 900 eV corresponds to the group of final levels with $J^\pi = 2^+$ or 5^+.

We conclude that the spin and parity assignment of the level at 1971.9 keV is 2^+.

A corresponding state in ^{148}Sm has been previously observed by Gelletly and Kane[22]. They proposed a $J = 2$, 3 or 4 state at 1970.9 keV with no parity assignment.

Buss and Smither[23] observed 6168.5 keV primary transition in their measurement with the natural target, but they ascribed this transition to ^{150}Sm. The intensity of the 6168.5 keV transition led to a 3^+ or 4^+ assignment for a state of ^{150}Sm established at 1818.9 keV.

The detailed inspection of the data presented in Ref. 23 shows that the intensity of the 6168.5 keV transition divided by E_γ^5 is 1.39 times higher than the mean value of intensities of the remaining transitions to the 3^+ or 4^+ states in ^{150}Sm.

In the earlier paper Smither[34] reported a level of ^{150}Sm at 1821.8 keV with a tentative assignment $J^\pi = 3^+$. The discrepancy between the excitation energy of this level and those equal to 1818.9 keV is accounted for in Ref. 23 by a possible closed doublet structure of the 6168.5 keV line. An inspection of the data accumulated by Bečvář et al.[32] has shown the presence of a 3^+ or 4^+ level in ^{150}Sm at 1819.9 keV. The existence of this level and the 2^+ level at 1971.9 keV in ^{148}Sm explains the doublet structure suggested in Ref. 23. These two states in the different nuclei account for the higher intensity reported in Ref. 23 for the 6168.5 keV line.

Level at 2032.3 keV. The 6108.3 keV transition observed in our spectra leads to a level at 2032.3 keV. Since this transition is observed in the resonances of both spin values and its intensity in the averaged spectrum rules out a 3^+ or 4^+ assignment, it follows from our data a 3^- or 4^- assignment for the 2032.3 keV level.

The data of Buss and Smither[23] are consistent with M-1 or E-1 character of the transition feeding their 2031.4 keV state. Harmatz and Handley[10] and Baba et al.[8] unambiguously assigned 4^-. However, since the recent study of ^{148}Eu decay by Adam et al.[11] yields a not unique 3^-, 4^- or 5^- assignment, we propose a $J^\pi = 4^-(3^-)$ assignment for the 2032.3 keV level.

Level at 2146.6 keV. This level is based on the observation of the 5994.0 keV transition in the resonances with both spin values. An intensity of this transition in the averaged spectrum excludes a negative parity assignment. Our data lead to a 3^+ or 4^+ assignment of the 2146.5 keV level.

Buss and Smither[23] proposed a 2146.4 keV level and a 3^+ or 4^+ assignment with preference for 4^+. Harmatz and Handley[10] and Baba et al.[8] assigned 5^+, while Cline[9] made only tentative 6^+ assignment. Both these assignments are in contradiction with our result and that of Buss and Smither[23]. However, Adam et al.[11] in their β-decay work proposed a 4^+ or 5^+ assignment.

The most probable value of the spin and parity of the 2146.6 keV level is 4^+.

Level at 2208.4 keV. This level is based on the presence of 5932.2 keV transition in our spectra. Since the transition is observed only in the 3^- resonances and its intensity in the averaged spectrum corresponds to the group of the 2^+ or 5^+ levels, the 2208.4 keV state has a 2^+ assignment.

This state was detected by Buss and Smither[23], who reported a 5932.9 keV transition. However, they were only able to assign ambiguously this transition to either ^{148}Sm or ^{150}Sm. The possible level at 2208.7 keV which they proposed was consistent with a 2^+ or 5^+ assignment.

In their (p,t) study Debenham and Hintz[14] reported a 0^+ level at 2206 ± 4 keV. Their assignment is based on the observation of two distinct maxima at 25° and 60° in an angular distribution of the triton group populating the 2206 keV level. The occurrence of these maxima is typical for the 0^+ final levels. On the other hand, an inspection of their data shows that appart from the 0^+ pattern the angular distribution contains another component decreasing strongly with the angle. This component resembles the angular distribution of the triton groups populating the 2^+ levels. The data of Debenham and Hintz[14] are therefore compatible with the exitence of a doublet formed by the 0^+ and 2^+ levels at 2206 keV.

The 2208.4 keV level in ^{148}Sm with a 2^+ assignment is now firmly established by our data.

Level at 2213.2 keV. This level is based on the observation of the 5927.4 keV transition in 4^- resonances. Since the relative intensity of the transition in the averaged spectrum corresponds clearly to the group of the 2^+ or 5^+ levels and is in contradiction with the 3^+ or 4^+ assignment, the 5^+ assignment of the 2213.2 keV level is deduced.

Buss and Smither[23] reported a 2212.7 keV level with a 2^+ or 5^+ assignment. However, they claimed that the reported level was established by a not unique decomposition of a complex structure in their averaged spectrum. Groshev et al.[21] observed the 5926 keV transition with 0.01 % intensity an deduced a level at 2216 keV, but they made no conclusions about the spin.

Baba et al.[8] and Harmatz and Handley[10] reported a 5^+ assignment for their level at 2215 and 2214.8 keV, respectively, while Cline[9] found a 2214.2 keV level with $J^\pi = 4^+$. A recent repetition of the same experiment as in Ref. 9 done by Adam et al.[11] yielded no spin and parity assignment.

The 5^+ assignment of the 2213.2 keV level is now well established.

Level at 2314.5 keV. This level is based on the presence of the 5826.1 keV transition. The transition is observed only in 3^- resonances. Its intensity in our averaged spectrum belongs to the group of the positive-parity levels.

Buss and Smither[23] found a 2^+ or 5^+ assignment for their 2314.2 keV level and prefered the 2^+ assignment, since Veje et al.[16] had observed the level in the (d,d') reaction.

Cline[9] assigned a negative parity, which was definitely ruled out by the results of the present experiment and some others -- as summarized in Ref. 23.

Harmatz and Handley[10] assigned $J^\pi = 4^+$, but only as a most probable choice, while Adam et al.[11] in their more recent work made no assignment.

The assignment made in Ref. 23 in combination with our resuls gives $J^\pi = 2^+$ for the 2314.5 keV level.

Level at 2327.1 keV. The 5813.5 keV transition populating this level is observed in resonances of both spin values. The intensity of the transition in our averaged spectrum corresponds clearly to the group of the 3^+ or 4^+ levels.

Buss and Smither[23] observed the 5813.6 keV line corresponding to their 2328.0 keV level. Since other closed strong lines originating from the ground state transition in ^{155}Sm was present, the authors were only able to make a limitation on the assignment and excluded $J^\pi = 3^+$ or 4^+ for the 2328.0 keV level.

Gelletly and Kane[22] observed a transition leading to a state at 2326.8 keV and excluded a J = 2 assignment. Harmatz and Handley[10], Cline[9] and Adam et al.[11] reported a level at the energies of 2328.0, 2326.9 and 2326.9 keV, respectively, and all of them assigned 4^+.

The only contradiction in the assignments arises from the exclusion of $J^\pi = 3^+$ or 4^+ made in Ref. 23. This exclusion was based on the separation of two components of the 5813.6 keV line belonging to ^{148}Sm and ^{155}Sm. On such separation Buss and Smither[23] assumed that the component of the 5813.6 keV line belonging to the G.S. transition in ^{155}Sm is of the same size as another line corresponding to the transition to the $1/2^-$ first excited level.

However, a large average spacing between the resonances for even-even nuclei can cause quite appreciable residual Porter-Thomas fluctuations in the transition intensities. For the neighbour target nuclei of ^{149}Sm Buss and Smither[23] reported the 10 % residual fluctuation. According to Karzhavina and Popov[30] and Rahn et al.[35] the mean spacing for ^{149}Sm and ^{154}Sm targets are equal to 2.3 ± 0.3

and 115 ± 8 eV, respectively. It is therefore expected that the average intensities of the transitions in ^{155}Sm will fluctuate with a relative R.M.S. of 70 %. Since an absolute contribution of the ^{155}Sm component in the 5813.6 keV line is at least as large as that of ^{148}Sm, such broad fluctuation do not permit to draw any conclusion about the spin of the 2328.0 keV state from the data in Ref. 23.

The present authors conclude, that the spin and parity of the 2327.1 keV level is 4^+.

Level at 2338.8 keV. The 5801.8 keV transition populating this level is observed in the resonances of both spin values, namely in the resonances at 3.4 and 18.3 eV. The intensity of the 5801.8 keV line in the averaged spectrum excludes the $J^\pi = 3^+$ or 4^+ assignment.

Our data lead to the 3^- or 4^- assignment for the 2338.8 keV level. This conclusion is in accordance with a tentative 3^- or 4^- assignment reported for a 2336 keV level in the (d,d') work by Veje *et al.*[16].

Buss and Smither[23] reported a 2338.6 keV level and proposed a $J^\pi = 2^+, 5^+, 3^-$ or 4^- assignment. Since the level had been observed in the (d,d') reaction, authors in Ref. 23 prefered the natural-parity 2^+ or 3^- assignment.

There are no other papers reporting the discussed level.

Level at 2381.2 keV. A strong 5759.4 keV line populating the 2381.2 keV level is present in 3^- resonances, while no trace of this line is observed in 4^- ones. The intensity of the 5759.4 keV line in the averaged spectrum corresponds to the group of the positive--parity levels. This leads to a 2^+, 3^+ or 4^+ assignment of the 2381.2 keV level with a strong preference for the value of 2^+.

This level probably coincides with a 2378 keV level observed by Veje et al.[16] in the (d,d') reaction. No information about the 2381.2 keV level is in the literature at present.

Level at 2440.5 keV. This level is based on the observation of a weak 5700.1 keV line in the averaged spectrum and in the spectrum from the 3^- resonance at 140 eV. A probability, that the line in the averaged spectrum results from random fluctuations is equal to 0.38 %. A weak intensity of the 5700.1 keV line excludes with certainty the 3^+ or 4^+ assignment of the 2440.5 keV level. In addition, a probability that the 2^+or 5^+ assignment is possible was estimated to be equal to 0.60 %.

Buss and Smither[23] reported a weak 5701.7 keV line leading to a 2440.7 keV level with a tentative 3^- or 4^- assignment. Our additional inspection of the data in Ref. 23 has shown that a 2^+ or 5^+ assignment is highly unprobable, so that an alternative assignment following from Ref. 23 is 2^- or 5^-.

Our data confirmed the existence of the level proposed by the authors in Ref. 23. A combination of our results with those in Ref. 23 leads to the 2^-, 3^- or 4^- assignment of the 2440.5 keV level.

The 2440.5 keV level probably coincided with the 2442.9 keV level reported by Reddingius and Postma[20] in their thermal neutron capture study.

Level at 2524.8 keV. This level is based on the observation of the 5615.8 keV transition in resonances with both spin values. An intensities of this transition in our averaged spectrum excludes with certainty the negative parity for the 2524.8 keV level. Our data lead to the 3^+ or 4^+ assignment.

Buss and Smither[23] deduced a 3^+ or 4^+ assignment for their 2524.2 keV level with preference for 4^+.

Our assignment and that made in Ref. 23 are in contradiction with the results of Adam et al.[11] and Cline[9], who assigned 3^- or 4^- and 4^- respectively. Harmatz and Handley[10] proposed a 4^+ assignment.

Available data lead to the most probable choice $J^\pi = 4^+$ for the 2524.8 keV level.

Level at 2538.7 keV. The 5601.9 keV transition populating this level is observed only in 3^- resonances. The average intensity corresponds to the group of the positive-parity levels.

The intensity of a 5603.2 keV transition observed in the experiment of Buss and Smither[23] led to a 2^+ or 5^+ assignment for their 2538.4 keV level. Since such level had not been detected in the (d,d') reaction, authors in Ref. 23 prefered the 5^+ assignment. Debenham and Hintz[14] in their recent study of the (p,t) reaction found a 2540 keV level and proposed a tentative 2^+ assignment. There are no other papers reporting the discussed level.

A combination of our results with those in Ref. 23 leads to an unambiguous 2^+ assignment for the 2538.7 keV level.

Level at 2569.3 keV. This level is based on a weak 5571.3 keV line observed in the averaged spectrum. A probability of originating of this line from random fluctuations is equal to 0.13 %. The intensity of the line excludes a $J^{\pi} = 3^+$ or 4^+ assignment for the 2569.3 keV level.

Buss and Smither[23] reported a 5572.1 keV transition associated with either ^{148}Sm or ^{150}Sm. For the case of ^{148}Sm they deduced a 3^- or 4^- assignment for a 2570.3 keV level. Levels at 2570.5 and 2569.1 keV were reported by Cline[9] and Adam et al.[11], respectively.

The results of the present work confirmed the existence of the 2569.3 keV level in ^{148}Sm and are consistent with the 3^- or 4^- assignment made in Ref. 23.

Level at 2608.3 keV. This level is deduced from the observation of the 5532.3 keV line in the 3.4 eV resonance. Though this line is weak, it is still well established, since the relative error of its area is only 22 %.

The intensity of the 5532 keV line in the averaged spectrum clearly corresponds to the group of the negative-parity levels. Our data lead to the 2^-, 3^- or 4^- assignment for the 2608.3 keV level. This level has not been detected in previuos experiments.

Level at 2633.0 keV. The 5507.6 keV transition populating this level is observed in 3^- resonances. The intensity of the transition in the averaged spectrum is by 4 % lower than the expectation value for the 2^+ or 5^+ levels. The observed intensity excludes with certainty the negative-parity assignment and rules out the 3^+ or 4^+ assignment within the confidence limit of 99.6 %. In addition, the values of "observed" intensities of the 5507.6 keV line in 4^- resonances are compatible with the value of zero, which is an argument for exclusion of the $J^\pi = 3^+$, 4^+ or 5^+ assignment. We therefore establish $J^\pi = 2^+$ for the 2633.0 keV level.

Buss and Smither[23] reported a 5509.2 keV line as the doublet consisting of the E-1 transitions in ^{148}Sm and/or ^{150}Sm. An inspection of the data accumulated by Bečvář et al.[32] has shown that one component of this doublet belongs to the E-1 transition populating the 2480.5 level of ^{150}Sm with $J^\pi = 3^+$ or 4^+. An average intensity of the composed 5509.2 keV line reported in Ref. 23 is in excellent agreement with the predictions following from the 3^+ or 4^+ assignment of the level in ^{150}Sm and the 2^+ assignment of the 2633.0 keV level in ^{148}Sm. Groshev et al.[21] observed a weak 5510 keV transition populating their 2632 keV level of ^{148}Sm. Cline[9] reported a 2634.2 keV level, however, made no assignment. It seems unlikely, that it is our reported 2633.0 keV level, since the 2^+ levels are not directly populated in β^+-decay of ^{148}Eu.

Level at 2640.5 keV. The 5500.1 keV transition populating this level is observed only in 4^- resonances. The intensity of the transition in the averaged spectrum corresponds to the group of the positive-parity levels with the strong preference for the 2^+ or 5^+ levels. An upper limit of an average intensity in 13 resonances with $J^\pi = 3^-$ was estimated to be equal to 25 % of the value expected for the E-1 transitions, which excludes the assignment $J^\pi = 2^+$, 3^+ or 4^+ for the 2640.5 level within the confidence limit of 99.68 %.

Buss and Smither[23] reported a 5502.2 keV transition. Since the 5502.2 keV line was obscured by other closed line originating from ^{151}Sm, the authors in Ref. 23 made only a tentative 2^+ or 5^+ assignment for a level deduced at 2639.4 keV. Groshev et al.[21] reported a 5501 keV transition with a 0.13 % intensity and deduced a 2641 keV level, however, they made no assignment. Harmatz and Handley[10], Cline[9] and Adam et al.[11] reported levels at 2641.4, 2640.5 and 2640.5 keV, respectively. Data in Ref. 10 allowed to restrict the spin and parity of the 2641.4 keV level to the most probable choice of 5^+, while the data of Cline[9] led to a tentative J = 4 or 6 assignment. No assignment was made in more recent experiment by Adam et al.[11].

Present data in combination with ones of other authors lead to almost certain 5^+ assignment for the 2640.5 keV level.

Level at 2646.4 keV. The 5494.2 keV transition is observed in the resonances of both spin values. The intensity of the transition in the averaged spectrum corresponds to the group of the positive-parity levels. Our data lead to the 2646.4 keV level with $J^\pi = 3^+$ or 4^+ assignment.

Buss and Smither[23] reported a 5497.3 keV transition and ascribed it ambiguously to either ^{148}Sm or ^{150}Sm. For the case of ^{148}Sm they deduced a 3^+ or 4^+ assignment. No other author reported the 2646.4 keV level.

Level at 2682.2 keV. The 5458.4 keV transition populating this level is observed in resonances of both spin values. The intensity of this transition in the averaged spectrum corresponds to the group of the positive-parity levels. Our data lead to the 3^+ or 4^+ assignment.

Groshev et al.[21] reported level at 2682 keV. Cline[9], Harmatz and Handley[10] and Adam et al.[11] reported levels at 2683.1, 2683.5 and 2683.1 keV, respectively. Data in Ref. 10 led to the most probable choice of $J^{\pi} = 4^{+}$, which is in agreement with our results.

Level at 2712.9 keV. The 5427.7 keV transition observed in the resonances of both spin values leads to the 2712.9 keV level. Since the intensity of the transition clearly corresponds to the positive-parity levels, a 3^{+} or 4^{+} assignment is deduced.

A level at 2712 keV was reported by Groshev et al.[21]. The 2712.9 keV level probably coincides with the 2711 keV level reported by Veje et al.[16].

Level at 2723.5 keV. This level is deduced from the 5417.1 keV transition observed in the spectra from resonances of both spin values. The intensity of the transition in the averaged spectrum corresponds to the group of the positive-parity levels. Our data lead to the 3^{+} or 4^{+} assignment.

Groshev et al.[21] reported a 2723 keV level. The authors in Refs. 9, 10, 11 reported levels at 2723.2, 2724.2 and 2723.2 keV, respectively. Data of Harmatz and Handley[10] led to the most probable choice of $J = 4$, which is not in disagreement with our assignment.

Level at 2828.0 keV. This level is established by the observation of the 5312.6 keV line in the spectrum of the 49.3 eV resonance. The intensity of the line in the averaged spectrum excludes a 3^{+} or 4^{+} assignment. Since the 4^{-} assignment of the 49.3 eV resonance is only tentative, our data lead to the 3^{-}, 4^{-}, $5^{\pm}$ or, possibly,

$2^{\pm}$ assignment for the 2828.0 keV level. There are no other papers reporting this level.

Level at 2835.2 keV. The existence of this level is based on the presence of the 5305.4 keV line in the 3^- resonances. The intensity of this line in the averaged spectrum excludes a negative parity and strongly prefers the 2^+ or 5^+ assignment of the 2835.2 keV level. We conclude that the assignment of the level is 2^+ or, possibly, 3^+ or 4^+. There are no other papers reporting this level.

Level at 2844.7 keV. This level is established from the observation of the 5295.9 keV transition in the 3^- resonances at 3.4 and 57.9 eV. The intensity of the transition in the averaged spectrum corresponds to the group of the negative-parity levels. Our data lead to the 2^-, 3^- or 4^- assignment for the 2844.7 keV level. No other papers report this level.

Level at 2978.8 keV. This level is deduced from the observation of the 5161.8 keV transition in a number of 4^- resonances. Since the intensity of the transition in the averaged spectrum is equal to the value expected at average for the transitions to the 2^+ or 5^+ levels, the negative parity of the 2978.8 keV level is excluded. An upper limit of the intensity of the 5161.8 keV transition averaged over 13 resonances with $J^{\pi} = 3^-$ is at least 5.8 times lower than it is expected for the E-1 transitions from the 3^- resonances. This justifies exclusion of 2^+, 3^+ and 4^+ assignments within the 99.92 % confidence limit. Our data lead to the 5^+ assignment of the 2978.8 keV level. The level has not been observed in the previous experiments.

New levels. The present experiment revealed 11 new levels. Five of them were already discussed in detail. Another level was found at 2672.7 keV with $J^{\pi} = 3^+$ or 4^+. The rest five levels are located above the excitation of 2350 keV. All new levels are included in Table II.

Not confirmed levels. Taking together all information extracted from β-decay in Refs. 1 - 11 and from the nuclear reactions with charged particles in Refs. 12 - 19, we can find a number of levels which have not been detected by the present experiment. However, most of these levels have an assignment which excludes direct population from the capturing states by dipole transitions. Other part of the undetected levels have no or only tentative assignment and it is therefore uncertain whether they have to be observed in our experiment. Only the rest levels at 2802.6, 2816.6 and 2831.6 keV should be observed, since according to Harmatz and Handley[10] single most probable chioces of spin and parity for these levels are 5^+, 4^+ and 5^+, respectively. All three levels were reported in Refs. 9, 10. Cline[9] made no firm assignments. In more recent work Adam et al.[11] deduced a 4^+ or 5^+ assignment for their 2830.5 keV level, while made no assignment for the rest two levels. It is difficult to judge how firm are the conclusions about the spin and parity made by the authors in Ref. 10. We only note that the unambiguous assignments made by Harmatz and Handley[10] for other levels at 2146.6 and 2314.5 keV were erroneous. On the other hand, our measurement does not excludes the possibility of missing some levels situated above the 3000 keV excitation.

The other class of the levels not confirmed by our measurement are those deduced from the (n,γ) experiments. In their averaged spectrum Buss and Smither[23] observed transitions at 6061.3, 5983.6, 5968.2 and 5628.2 keV and ascribed them ambiguously to either ^{148}Sm or ^{150}Sm. For the case of ^{148}Sm they deduced levels at 2080.3, 2158.0, 2173.4 and 2513.4 keV with a 2^+ or 5^+ assignment for the first three levels and 3^+ or 4^+ assignment for the last level. None of the four levels have been found in the present measurement. However, Bečvář et al.[32] reported two 2^+ levels at 1927.3 and 2005.5 keV in ^{150}Sm. Besides that, an inspection of the original data accumulated in Ref. 32 has shown that there are two additional levels in ^{150}Sm at 2020.4 and 2360.3 keV with assignments 5^+ and 3^+ or 4^+, respectively. The existence of these four levels in ^{150}Sm and their assignments explained the presence of the above mentioned primary transitions reported in Ref. 23.

It should be mentioned that Buss and Smither[23] reported also very weak (40 % uncertainty in intensity) 6708.9 keV line and deduced a 1433.5 keV level with a 1^-, 6^-(2^-, 5^-) assignment. Our measurement did not detect this level. Kenefick and Sheline[12] on the basis of the (d,p) and (p,p') data reported a 1432 keV level, however, made no assignment. It is highly probable that the 1432 keV level is identical with 0^+ level at 1426 ± 3 keV reported recently in the (p,t) work by Debenham and Hintz[14].

Gelletly and Kane[22] who studied the neutron capture gamma-ray spectrum of the 3.4 eV resonance observed transitions at 5999.1 and 6493.0 keV and deduced levels at 2142.5 and 1648.6 keV. None of these two levels have been observed in the present experiment, though roughly the same statistical accuracy was achieved in our 3.4 eV spectrum and in spite of the fact that other 22 resonant spectra were available. It is probable that the two levels reported in Ref. 22 are spurious. Possible consequencies have been already discussed in connection with the 1453.0 keV level.

Groshev et al.[21] detected a number of levels which were not confirmed by our measurement. These levels are based on the observation of very weak lines in the thermal spectrum. Since no errors in intensities of the lines are presented in Ref. 21, it is not certain whether these lines are established firmly. All levels detected by the authors in Ref. 21 below 3110 keV are listed in Table II.

Positive-parity levels. The present knowledge of the ^{148}Sm level system is based on rich information from a broad variety of experiments. As it was already emphasized in the Introduction, the efficient experiment for the detection of $J^{\pi} = 2^+, 3^+, 4^+$ or 5^+ levels was that of Buss and Smither[23]. Since our experiment included all resonannces below 900 eV, it serves as another highly efficient and independent source of information about ^{148}Sm levels.

Our data in combination with those accumulated by Bečvář et al.[32] made possible to solve all uncertainties in the isotopic assignment reported by Buss and Smither[23] for some E-1 transitions. For details see Table II and the discussion of the particular levels.

Comparison of our results with those in Ref. 23 and rough estimation of the detection sensitivity of our experiment led us to the strong believe that the set of the $J^{\pi} = 2^+, 3^+, 4^+$ or 5^+ levels, which we detected below 2600 keV, is complete.

Negative-parity levels. Nine negative-parity levels, populated directly by primary M-1 transitions have been detected by the present experiment. Besides three new levels reported for the first time, our data allowed to confirm the existence of other two levels which had not been established firmly. In addition, new information have been obtained about the spin of the negative-parity levels. For the details see Table II and the discussion to the particular levels.

It should be stressed that we were able to observe the transitions to all six $J^{\pi} = 2^-, 3^-, 4^-$ or 5^- levels proposed by previous works, including those levels which had been established tentatively. The intensities of the transitions were in most cases statistically well defined. Errors of the intensities were usually below 10 to 20 %. The exceptions are weak intensities of the transitions to the levels at 2440.5 and 2569.3 keV. However, as it has been apparent from the detailed discussion to these levels, even in this case the intensities were significantly different from the value of zero. All previously proposed levels are located below the 2600 keV excitation.

Both, the observation of the transitions to all previously known $J^{\pi} = 2^-, 3^-, 4^-$ or 5^- levels and the statistical significance of the transition intensities prove high sensitivity of the present experiment to detect the negative-parity levels below the 2600 keV excitation. Hence, it is highly probable that the set of the negative-parity levels with $J^{\pi} = 2^-, 3^-, 4^-$ or 5^- below 2600 keV detected by the present experiment is complete.

V. DISCUSSION OF RESULTS AND CONCLUSIONS

The present experiment enlarged the information about the ^{148}Sm levels. Of 50 levels obseved, substantially new limits were set on the spin and parity of 25 levels. The assignment of part these levels was made unambiguously -- the values 2^+ and 5^+ were ascribed to 7 and 3 levels, respectively. These 2^+ levels were not observed in the β-decay experiments, since the levels are situated at relatively high excitations and are not populated directly by the β-transitions. The 2^+ and 5^+ assignments of the levels may turn to be useful as starting points in interpretation of future experimental data. It should be stressed in this connection that high precision low-energy capture gamma-ray measurements and corresponding electron conversion measurements are still lacking.

A most detailed calculation concerning the positive-parity levels which is available at present is that of Kenefick and Sheline[12] based on the use of the asymmetric rotor model of Davydov and Chaban[36]. The asymmetry parameter γ and the nonadiabaticity parameter μ were adjusted for the fit of the first 2^+ and first 4^+ levels. Comparison of the calculated level system with the experimental positive-parity levels determined by the present work and by previous studies is shown in Fig. 8. Though the results of the original comparison of the calculated levels with the experimental (d,p) and (p,p') data of Kenefick and Sheline[12] was satisfactory, the present available data give rather poor agreement. This is mainly due to the first 0^+, second 2^+ and first 3^+ levels, since these are located about 250 keV higher than it was suggested by the old data in Ref. 12. Nevertheless, it should be stressed that the asymmetric rotor model successfully predicts the spins of all positive-parity levels below 1900 keV. In addition, the first 5^+ level is expected at 2041 keV, which is in qualitative agreement with our detection of the first 5^+ level at 2213.2 keV.

Our data lead to the 2^+ assignment of the 1453.0 keV level. According to purely vibrational treatment of the level system, this level and the 4^+ level at 1180.3 keV could be identified with the 2^+ and 4^+ members of the two-phonon triplet. However, Groshev et al.[21] proposed the 1453.0 keV level as a head of the quasi-gamma band.

In order to clarify the role of the two-phonon vibrations, let us turn our attention to a 0^+ member of a possible two-phonon triplet. The candidates for this member are the 0^+ level at 1426 keV detected recently by Debenham and Hintz[14] in the (p,t) measurement and 0^+ level at 1120 keV proposed by Yshizaki et al.[13], also on the basis of the (p,t) data. There are three reasons why the existence of the latter 0^+ level is uncertain. First, the resolution power of 100 keV for tritons in the experiment of Yshizaki et al.[13] was insufficient and could not provide separation of the triton group feeding the 1120 keV level from two groups corresponding to the 3^- and 4^+ levels at 1161.7 and 1180.3 keV, respectively. Second, there were no traces of the triton group corresponding to 1120 keV level in high resolution (8 keV FWHM) data from the (p,t) work by Debenham and Hintz[14]. Third, no other authors reported this level, except Kenefick and Sheline[12], who, in an attempt to find the predicted 0^+ level at 1128 keV (see Fig. 8), stated only weak evidence in some of the (d,p) spectra for a level with unknown spin at ~1120 keV. The 0^+ level at 1426 keV as the remaining candidate is strongly populated in the ^{150}Sm(p,t)^{148}Sm reaction. The intensity of the triton group for this level is equal to 18 % of the intensity for the ground state and, according to Ref. 14, is by an order of magnitude higher than it is expected for the two-phonon 0^+ level. Due to the high intensity the 1426 keV level cannot be identified with the missing 0^+ member of the triplet. In their analysis of the two-neutron transfer reactions Takemesa et al.[37] suggested coexistence of spherical and deformed components in the ground state of ^{150}Sm. This led Debenham and Hintz[14] to an interpretation of the 0^+ 1426 keV level as a deformed shape isomer which gives a favourable overlap with the deformed component of the target ground state and explains the enhanced (p,t) intensity. This interpretation is supported by Sheline et al.[38], who gave indication that the shape isomerism exists in Mo and Zr nuclei.

It follows from above explained arguments that the existence of the 0^+ member of the two-phonon triplet is uncertain and, hence, the question about the two-phonon structure of the levels around 1300 keV is open. We can assume, that there exists some other low--lying 0^+ level, which has not yet been detected. However, if the shape isomerism is present, then a simple description of this presumably unknown 0^+ level and the levels at 1453.0 and 1180.3 keV in terms of the pure two-phonon quadrupole vibrations would not be justified.

Irrespective of the difficulties with the two-phonon quadrupole vibrations, the present authors tested the possibility of occurrence of two-phonon quadrupole-octupole levels in ^{148}Sm.

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Irrespective of the difficulties with the two-phonon quadrupole vibrations, the present authors tested the possibility of occurrence of two-phonon quadrupole-octupole levels in ^{148}Sm.

The two-phonon quadrupole-octupole levels form a quintet with spins and parities 1^-, 2^-, 3^-, 4^- and 5^-. In harmonic approximation it is expected that the levels are situated around the excitation energy equal to the sum of the energies of the first 2^+ and first 3^- levels. So far, no case was reported where all members of the quintet had been detected. In order to observe these levels and not to mix them with two-quasiparticle negative-parity levels, they should be centered around an excitation which is lower than the energy corresponding to the breaking of the first nucleon pair. Since the energy of the first 2^+ level increases as the nucleus becomes spherical and, on the other hand, the vibrational structure fades as the nucleus becomes deformed, conditions for observation of the two-phonon quintet are fulfilled in the transitional region. The level systematics of Sakai[39] suggests that the best candidates in the vicinity of N = 82 shell are ^{146}Nd, ^{148}Sm and ^{150}Gd since the centre of the quintet for these nuclei should be situated at about 1660, 1710 and 1780 keV, respectively. In accordance with the results of Zolnowski et al.[40] who reported a developed quasirotational structure in ^{150}Sm and ^{152}Gd, these nuclei and also ^{148}Nd were already assumed as partially deformed.

The set of the negative-parity levels detected in our experiment, i. e. those with $J^{\pi} = 2^-, 3^-, 4^-$ or 5^-, is listed in Table II. The rasons for our expectation that this set is complete for the excitations up to 2600 keV have been already mentioned. In addition, Seeman et al.[17] and Veje et al.[16] found a 1^- level at 1465 keV. This was confirmed by Grigoriev et al.[6] who detected the 1464.5 keV level and made the 1^- assignment. It is reasonable to assume that this level is the 1^- member of the quintet. The 5^- member can be formed by the level at 1594.0 keV. In accordance with Table II the 3^- and 4^- members of the quintet can be formed by any pair selected from the levels at 2032.3, 2338.8, 2440.5 and 2569.3 keV with strong preference of the 2032.3 keV level for the 4^- member. The 2^- member can be selected only from the levels above 2600 keV, i. e. from 2608.3, 2828.0 or 2844.7 keV levels or from other undetected levels.

Lipas[41] treated phenomonologically splitting of the two-phonon quintet caused by an unharmonic interaction between the quadrupole and octupole phonons. For the case of unharmonicities of the third order (cubic) he has shown that a sequence of the levels (when an excitation energy increases) in the splitted quintet is 4^-, 1^-, 5^-, 2^- with an arbitrary position of the 3^- member. On the other hand, no general rule concerning the level sequence has been derived for the unharmonicities of the fourth order, except that the assignment of the first level should be 1^-.

Răduţă <u>et al.</u>[42] developed a semimicroscopic theory of quadrupole and octupole phonons based on the Hamiltonian with pairing, quadrupole and octupole forces. In analogy with the phenomenological approach authors in Ref. 42 added to the Hamiltonian a new term, cubic in the multipole moments, simulating the quadrupole-octupole interaction. Using an iteration procedure they calculated the splitting of the quintet for the case of ^{114}Sn with the closed proton shell Z = 50 and obtained a level sequence 4^-, 2^-, 1^-, 5^-, 3^-. However, the authors in Ref. 42 did not exclude possibility that higher iterations can lift up the 2^- level and give the level sequence similar to that yielded by the purely phenomenological model with the cubic interaction.

As a next step, Răduţă and Săndulescu[43] developed a complete semimicroscopic theory which inherently includes unharmonicities and, in contrast to that developed in Ref. 42, does not require adding of the phenomenological unharmonic quadrupole-octupole term. Owing to this feature the complete semimicroscopic theory made it possible to predict the size of the quintet splitting. Calculations performed in Ref. 43 for ^{114}Sn included the unharmonicities of up to fourth order and led to the level sequence 2^-, 1^-, 3^-, 5^-, 4^- with a possible interchange of the 1^- and 3^- members. The size of the overall splitting predicted by these calculations for ^{114}Sn is equal to ~800 keV. We note, that this value represents 34 % of the energy of the octupole phonons in ^{114}Sn.

So far, no calculations similar to those in Refs. 42, 43 have been done for ^{148}Sm. It is not certain, whether the level sequences obtained for ^{114}Sn are aplicable to the case of ^{148}Sm, nevertheless, it is worth noting that both level sequences proposed in Refs. 42, 43 are in contradiction with our experimental results. Since the data indicate that the 4^- level can be located only above the 5^- one, the experimental level sequence is also in contradiction with that following from the phenomenological model of Lipas[41] for the case of the cubic interaction.

If the two-phonon quadrupole-octupole structure occurs in ^{148}Sm, then, according to present data, the size of the total splitting is equal to or higher than ~1150 keV. Such value is as large as the energy of the octupole phonons. A question arises, whether the large splitting still allows to interpret corresponding levels in terms of vibrations. It is highly probable, that the spacing between the 1^- and 3^- members is equal to 870 keV or higher. We note that this value is at least three times higher than it was expected in Ref. 41 for ^{148}Sm on the basis of the old experimental data. Further, possible 3^- and 4^- members of the quintet are situated above 2000 keV excitation, while the 2^- member is even above 2600 keV. It suggests that the 2^-, 3^- and 4^- levels may contain admixtures of the two-quasiparticle states which occur at such excitations.

An alternative interpretation of the negative-parity levels was done by Adam et al.[19] on the basis of the (α,xn) data. They proposed a tentative quasi-rotational band formed by the levels at 1161.7, 1594.0, 2129 and 2807 keV with 3^-, 5^-, (7^-) and (9^-) assignments, respectively. As the spin and parity of the levels at 2129 and 2807 keV were not assigned firmly and no information about these levels has been reported, it is plausible that the 2807 keV level is identical with our 3^+ or 4^+ level at 2806.4 ± 0.6 keV.

We conclude that our data are not in accordance with the present available theoretical information about the two-phonon quadrupole-octupole vibrational levels in ^{148}Sm. As there are also difficulties in identification of the 0^+ member of the two-phonon triplet, it is not excluded that a possible distorsion of the quintet and that of the triplet has some common origin, e. g. the shape isomerism suggested by Debenham and Hintz[14].

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Table I. Spin assignments of neutron resonances in the $^{147}Sm(n,\gamma)^{148}Sm$ reaction.

E_{res} (eV)	Spin		
	Primary γ-rays	Secondary γ-rays	Composite
3.40	3	3	3
5.29		4	(4)
18.3	4	4	4
27.1	3	3	3
29.7	3	3	3
32.1	4	4	4
39.7	4	4	4
40.6	3	3	3
49.3	(4)	4	(4)
57.9	3	3	3
64.9	3	(4)	3 [a]
76.0	4	4	4
79.8	(4)	(3)	(4)
83.4	3	3	3
99.5	(4)	(4)	(4)
102.6	(3)	(3)	3 [b]
106.8	(4)	(4)	(4)
123.4	3	(3)	3
140.0	3	(3)	3
151.3	3	(3)	3
163.6	4	(4)	(4)
171.7	(3)	(4)	(4)[c]
183.7	3	3	3
205.8		(4)	(4)

[a] The 64.9 eV line is either a single 3^- resonance or a doublet with spins 3^- and 4^-. For details see the main text.

[b] On the basis of (n,α) measurements Yu.P.Popov et al.[29] made a 3^- assignment.

[c] Gamma-multiplicity measurement by A.B.Popov et al.[28] led to a 4^- assignment.

Table II. The levels of ^{148}Sm populated by primary E-1 and M-1 transitions in the ^{147}Sm(n,γ)^{148}Sm reaction. In column 10 only those values of spin and parity are listed which represent essentially new information in comparison with the assignments in column 9. The parentheses around some energies mean that existence of corresponding levels was not certain. Spins and parities in column 7 are based on an anylysis of the averaged spectrum, while the column 8 represents results yielded by the individual resonance spectra.

Present work			Ref. a	Ref. b	Ref. c	Spin and parity assignments of final states				
						Present work				
Line No.	E_γ (keV)	E_{exc} (keV)	E_{exc} (keV)	E_{exc} (keV)	E_{exc} (keV)	Average	Resonance	Ref. a	Refs. b,c	Composite
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	7590.3	550.3 ± 0.3	550.5	550.0	550.5	$2^+,5^+$	2^+	2^+		2^+
1a	6978.9	1161.7 ± 0.5	1162.2	1161.1		$2^-,3^-,4^-,5^-$	3,4	3^-		3^-
2	6960.3	1180.3 ± 0.3	1180.1	1180.2		$2^+,3^+,4^+,5^+$	$3^+,4^+$	4^+		4^+
			1433.5	1434.2				$1^-,6^-(2^-,5^-)$		0^+ ^{d}
3	6687.6	1453.0 ± 0.4	1453.6	1455.5	1453.6	$2^+,5^+$	$2^\pm(3^-,4^-)$	$2^+(5^+)$	2^+	2^+
3a	6546.5	1594.0 ± 0.4	1595.0	1593.5		$2^-,3^-,4^-,5^-$	5(3,4)	$3^-(4^-)$		5^- ^{d}
					1648.6 ^{e}				2,3,4	
4	6476.9	1663.7 ± 0.2	1663.4	1659.3	1663.4	$2^+,3^+,4^+,5^+$	2^+	$2^+(5^+)$	2^+	2^+
				1718.0 ^{e}						
5	6408.3	1732.3 ± 0.3	1732.9	1733.4		$2^+,3^+,4^+,5^+$	$3^+,4^+$	$4^+(3^+)$		$4^+(3^+)$
6	6246.0	1894.6 ± 0.3	1894.1	1894.1	1894.1	$2^+,3^+,4^+,5^+$	$3^+,4^+$	$3^+,4^+$		$3^+,4^+$
7	6237.6	1903.0 ± 0.3	(1902.9)^f			$2^+,3^+,4^+,5^+$	$3^+,4^+$	$3^+,4^+$		$3^+,4^+$
8	6168.9 ^{g}	1971.9 ± 0.3			1970.9	$2^+,5^+$	2^+		2,3,4	2^+
8a	6108.3	2032.3 ± 1.0	2031.4	2032		$2^\pm,3^-,4^-,5^\pm$	3,4	negative parity		$4^-(3^-)$ ^{d}
			(2080.3)^{f,h}					$2^+(5^+)$		
9	6030.3	2110.3 ± 0.2	2110.7	2111	2110.7	$3^+,4^+$	$3^+,4^+$	$3^+, 4^+$		$3^+,4^+$
					2142.5 ^{e}				2,3,4	
10	5994.0	2146.6 ± 0.2	2146.4	2147		$2^+,3^+,4^+,5^+$	$3^+,4^+$	$4^+(3^+)$		$4^+(3^+)$

Table II. (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
			(2158.0)[f,h]					$2^+,5^+$		
			(2173.4)[f,h]					$2^+,5^+$		
11	5932.2	2208.4 ± 0.4	(2208.7)[f]			$2^+,5^+$	2(3,4)	$2^+(5^+)$		2^+
12	5927.4	2213.2 ± 0.5	2212.7 [d]	2216		$2^+,5^+$	5(3,4)	$5^+(2^+)$		5^+
13	5913.2	2227.4 ± 0.3	2227.6	2228	2227.6	$2^+,3^+,4^+,5^+$	$3^+,4^+$	$4^+(3^+)$		$4^+(3^+)$
14	5826.1	2314.5 ± 0.6	2314.2			$2^+,3^+,4^+,5^+$	2(3,4)	$2^+(5^+)$		2^+
15	5813.5	2327.1 ± 0.3	2328.0	2327	2326.8	$3^+,4^+$	$3^+,4^+$	$2^{\pm},3^-,4^-,5^{\pm}$ [i]	2,3,4	4^+ [d]
15a	5801.8	2338.8 ± 0.4	2338.6			$2^{\pm},3^-,4^-,5^{\pm}$	3,4	$2^+,3^-(5^+,4^-)$ [i]		$3^-,4^-$
16	5759.4	2381.2 ± 0.3				$2^+,3^+,4^+,5^+$	$2^+(3^+,4^+)$			$2^+(3^+,4^+)$
17	5750.6	2390.0 ± 0.4	2389.2		2389.2	$2^+,3^+,4^+,5^+$	3,4	$3^+(4^+)$		$3^+(4^+)$
				2398 [e]						
17a	5700.1	2440.5 ± 0.7	2440.7	2441		$2^{\pm},3^-,4^-,5^{\pm}$	2,3,4	$(3^-,4^-)$		$3^-,4^-$ [d]
18	5652.5	2488.1 ± 0.7	2489.5			$2^+,3^+,4^+,5^+$	2,3,4	$3^+(4^+)$		$3^+(4^+)$
			(2496.3)[j,e]					$2^-,3^-,4^-,5^-$		
			(2513.4)[f,h]					$3^+,4^+$		
19	5615.8	2524.8 ± 0.5	2524.2	2525	2524.2	$3^+,4^+$	$3^+,4^+$	$4^+(3^+)$		$4^+(3^+)$
20	5601.9	2538.7 ± 0.6	2538.4			$2^+,3^+,4^+,5^+$	2(3,4)	$5^+(2^+)$		2^+
				2542 [e]						
20a	5571.3	2569.3 ± 1.5	(2570.3)[f]			$2^{\pm},3^-,4^-,5^{\pm}$		$3^-,4^-$		$3^-,4^-$
20b	5532.3	2608.3 ± 1.1				$2^-,3^-,4^-,5^-$	2,3,4			$2^-,3^-,4^-$
21	5507.6	2633.0 ± 0.6	(2632.4)[f,d]	2632		$2^+,5^+(3^+,4^+)$	2(3,4)	$(2^+,3^+,4^+,5^+)$		2^+ [d]
22	5500.1	2640.5 ± 0.9	2639.4	2641		$2^+,5^+(3^+,4^+)$	5(3,4)	$2^+,5^+$ [k]		5^+ [d]
23	5494.2	2646.4 ± 0.6	(2644.3)[f]			$2^+,3^+,4^+,5^+$	3,4	$3^+,4^+$		$3^+,4^+$
24	5467.9	2672.7 ± 0.6				$2^+,3^+,4^+,5^+$	3,4			$3^+,4^+$
25	5458.4	2682.2 ± 0.6		2682		$2^+,3^+,4^+,5^+$	3,4			$4^+(3^+)$ [d]
				2693 [e]						
26	5442.4	2698.2 ± 0.6				$3^+,4^+$	3,4			$3^+,4^+$
27	5427.7	2712.9 ± 0.7		2712		$2^+,3^+,4^+,5^+$	3,4			$3^+,4^+$

Table II. (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
28	5417.1	2723.5 ± 0.7		2723		$2^+,3^+,4^+,5^+$	3,4			$3^+,4^+$
29	5387.9	2752.7 ± 0.8		2754		$2^+,3^+,4^+,5^+$	5(3,4)			$5^+(3^+,4^+)$
30	5334.2	2806.4 ± 0.6		-		$3^+,4^+$	3,4			$3^+,4^+$
31	5326.4	2814.2 ± 1.0		2813		$2^+,3^+,4^+,5^+$	5(3,4)			$5^+(3^+,4^+)$
31a	5312.6	2828.0 ± 1.3				$2^\pm,3^-,4^-,5^\pm$	3,4,5(2)			$3^-,4^-,5^\pm(2^\pm)$
32	5305.4	2835.2 ± 1.6				$2^+,5^+(3^+,4^+)$	2(3,4)			$2^+(3^+,4^+)$
32a	5295.9	2844.7 ± 0.8				$2^-,3^-,4^-,5^-$	2,3,4			$2^-,3^-,4^-$
33	5279.4	2861.2 ± 0.2		2861		$3^+,4^+$	$3^+,4^+$			$3^+,4^+$
34	5274.4	2866.2 ± 1.0				$2^+,5^+$	2,3,4			2^+
				2891 [e]						
35	5222.4	2918.2 ± 1.0		2918		$2^+,3^+,4^+,5^+$	3,4			$3^+,4^+$
36	5213.1	2927.5 ± 0.9				$2^+,3^+,4^+,5^+$	3,4			$3^+,4^+$
				2966 [e]						
37	5161.8	2978.8 ± 1.2				$2^+,3^+,4^+$	5^+			5^+
38	5146.3	2994.3 ± 0.8		2992		$3^+,4^+$	3,4			$3^+,4^+$
39	5127.7	3012.9 ± 1.6				$2^+,5^+$	2(3,4)			2^+.
				3050 [e]						
				3063 [e]						
40	5053.1	3087.5 ± 1.1		3089		$2^+,3^+,4^+,5^+$	2(3,4)			$2^+(3^+,4^+)$
41	5032.9	3107.7 ± 1.0		3107		$3^+,4^+$	3,4			$3^+,4^+$

[a] D. J. Buss and R. K. Smither [23]. Spins and parities in Ref. 23 include also the results of other previous authors.

[b] L. V. Groshev et al. [21].

[c] . Gelletly and W. R. Kane [22].

[d] For explanation see the main text.

[e] The level is not confirmed by the present experiment.

[f] Primary transition was ascribed ambiguously to either ^{148}Sm or ^{150}Sm.

[g] The transition was not observed by Buss and Smither [23]. See the explanation in the main text.

[h] Data accumulated by F. Bečvář et al. [32] have indicated that the primary transition belongs to ^{150}Sm.

[i] The spectrum of Buss and Smither [23] is obscured by the transition in ^{155}Sm.

[j] An isotopic assignment of the primary transition was not certain.

[k] The spectrum of Buss and Smither [23] obscured by the transition in ^{151}Sm.

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FIGURE CAPTIONS

Figure 1. The time-of-flight dependence of the intensity of the 550.3 keV gamma-line. The line results from a decay of the 2^+ level at 550.3 keV to the ground state. Elimination of the influence of a Compton background in a gamma-ray spectrum is made.

Figure 2a. High-energy parts of the gamma-ray spectra from the individual resonances. Only DE peaks resulting from the capture in ^{147}Sm are lebelled. The labelling is identical with that used in Fig. 3 and Table II.

Figures 2b - 2e. High-energy parts of the gamma-ray spectra from the individual resonances. See also the caption in Fig. 2a.

Figure 3. The capture gamma-ray spectrum averaged over the neutron energies from 25 to 900 eV. Only DE peaks resulting from the capture in ^{147}Sm are labelled. Labelling is identical with that used in Figs. 2a - 2e and in Table II.

Figure 4. The ratio of the populations of the 1161.7 and 1180.3 keV levels and its systematic dependence on the capturing state spin. Spin assignments shown are identical with those in Table I.

Figure 5. Averaged reduced intensities of primary gamma--rays v. s. gamma-ray energy. The systematic dependence of the intensities on the spin and parity of final levels is apparent. The assignments used are identical with those in Table II.

Figure 6. A frequence distribution of the averaged reduced intensities of E-1 primary gamma-rays. For the explanation of the smooth curves, see the main text.

Figure 7. A comparison between the experimental positive-parity levels and those predicted by the Davidov-Filippov[36] theory. The parameters used in Ref. 12 for the calculation were $\gamma = 22.4^{\circ}$ and $\mu = 0.94$. Besides the levels observed in the present experiment, the 0^{+} and 6^{+} levels, reported in Refs. 10, 14, are included.

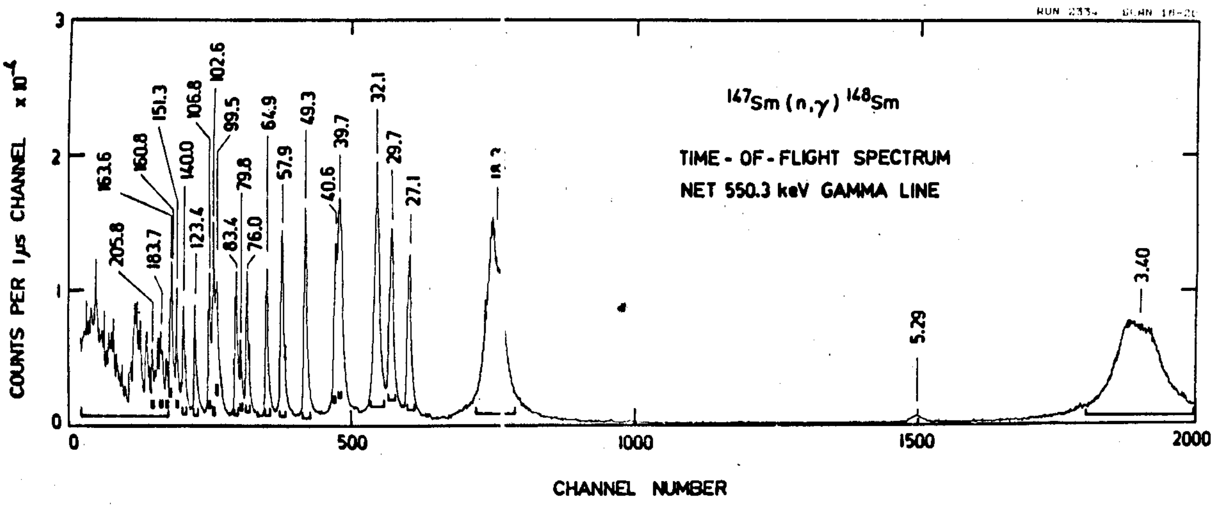

RUN 2334 SCAN 18-20
$^{147}Sm\,(n,\gamma)\,^{148}Sm$
TIME - OF - FLIGHT SPECTRUM
NET 550.3 keV GAMMA LINE
COUNTS PER 1μs CHANNEL x 10^{-4}
0
1
2
3
CHANNEL NUMBER
0
500
1000
1500
2000
205.8
183.7
163.6
160.8
151.3
140.0
123.4
106.8
102.6
99.5
83.4
79.8
76.0
64.9
57.9
49.3
40.6
39.7
32.1
29.7
27.1
18.3
5.29
3.40

FIG. 1

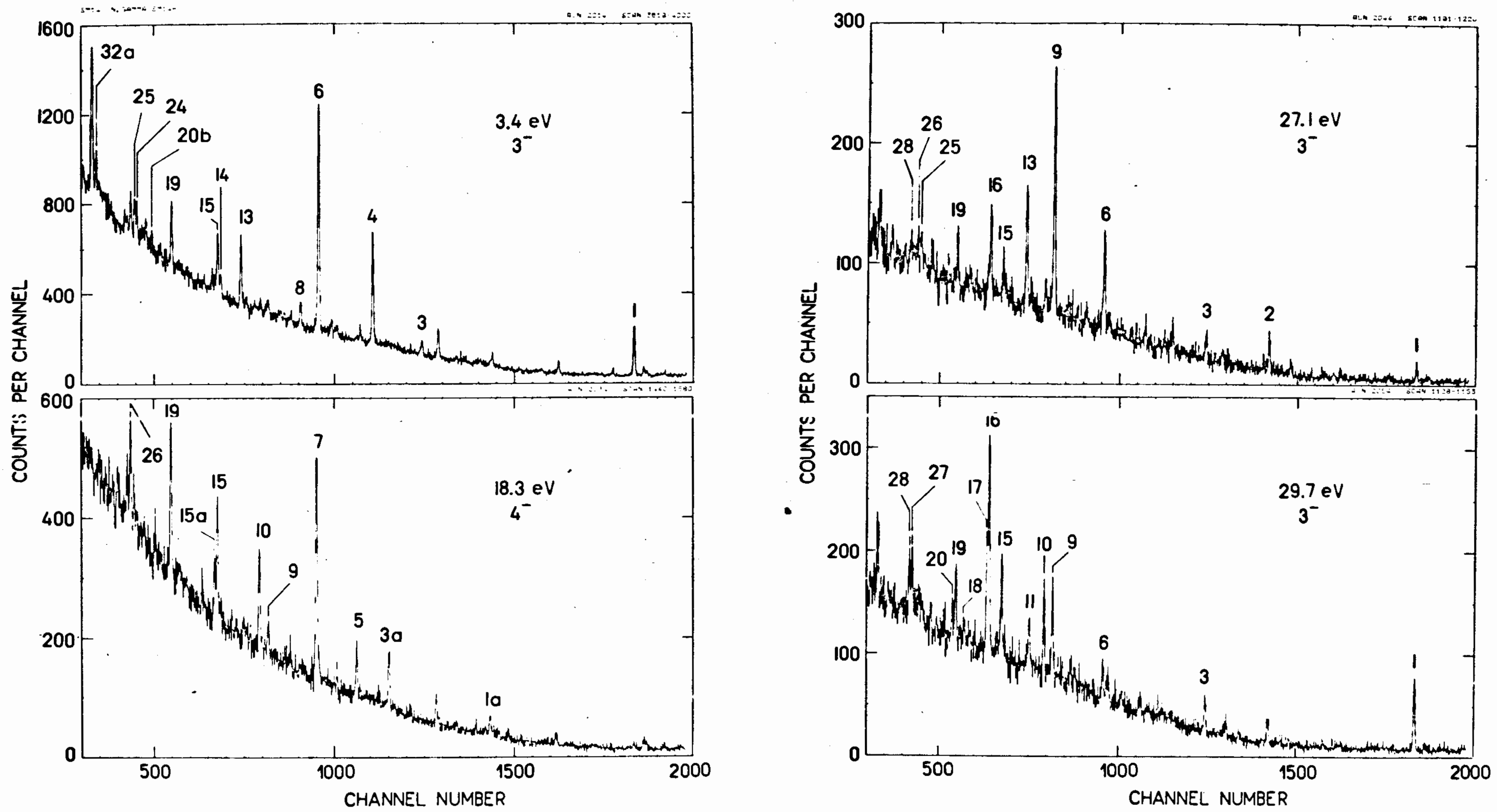

COUNTS PER CHANNEL
CHANNEL NUMBER
3.4 eV
3⁻
18.3 eV
4⁻
27.1 eV
3⁻
29.7 eV
3⁻
32a
25
24
20b
19
15
14
13
8
6
4
3
1
26
19
15a
15
10
9
7
5
3a
1a
28
26
25
19
16
15
13
9
6
3
2
1
28
27
20
19
18
17
16
15
11
10
9
6
3
1
0
400
800
1200
1600
200
600
100
300
500
1000
1500
2000

FIG. 2a

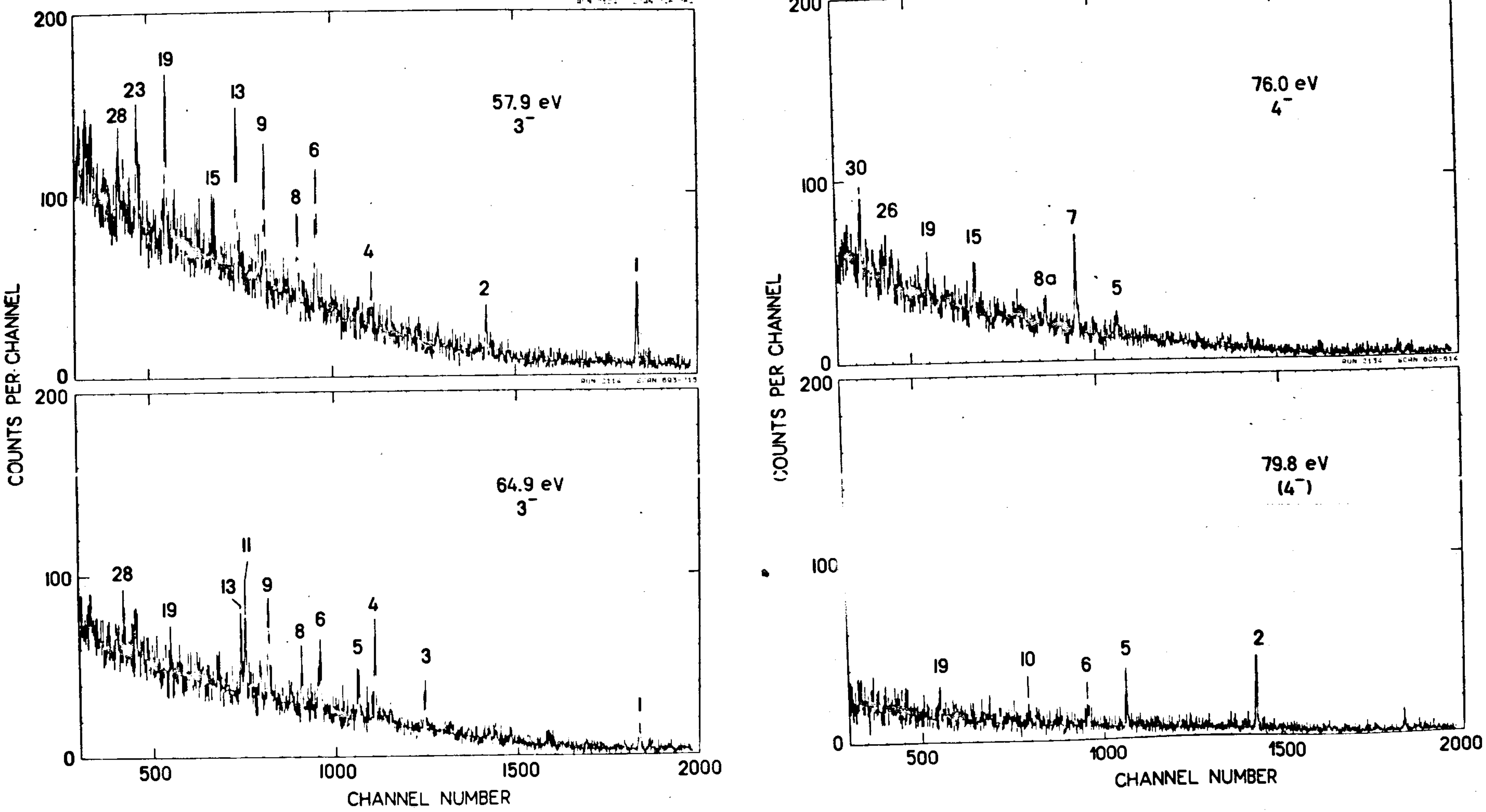

57.9 eV
3⁻
64.9 eV
3⁻
76.0 eV
4⁻
79.8 eV
(4⁻)
28
23
19
13
15
9
8
6
4
2
1
11
5
3
30
26
7
8a
10
COUNTS PER CHANNEL
CHANNEL NUMBER
0
100
200
500
1000
1500
2000

FIG. 2c

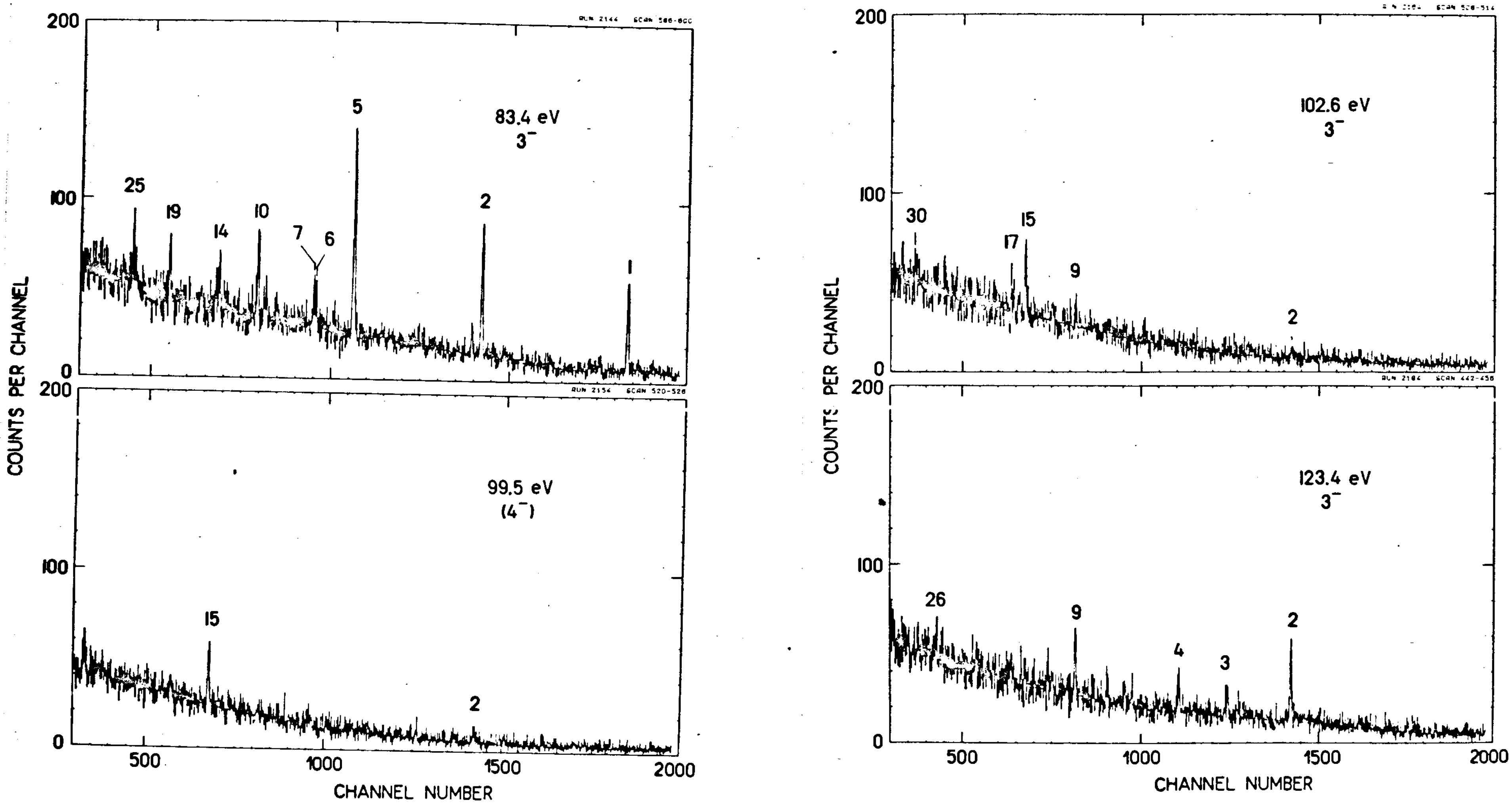

RUN 2144 SCAN 586-600
83.4 eV
3^-
25
19
14
10
7
6
5
2
1
RUN 2154 SCAN 520-526
99.5 eV
(4^-)
15
2
COUNTS PER CHANNEL
200
100
0
500
1000
1500
2000
CHANNEL NUMBER
RUN 2184 SCAN 528-514
102.6 eV
3^-
30
17
15
9
2
RUN 2184 SCAN 442-456
123.4 eV
3^-
26
9
4
3
2

FIG. 2d

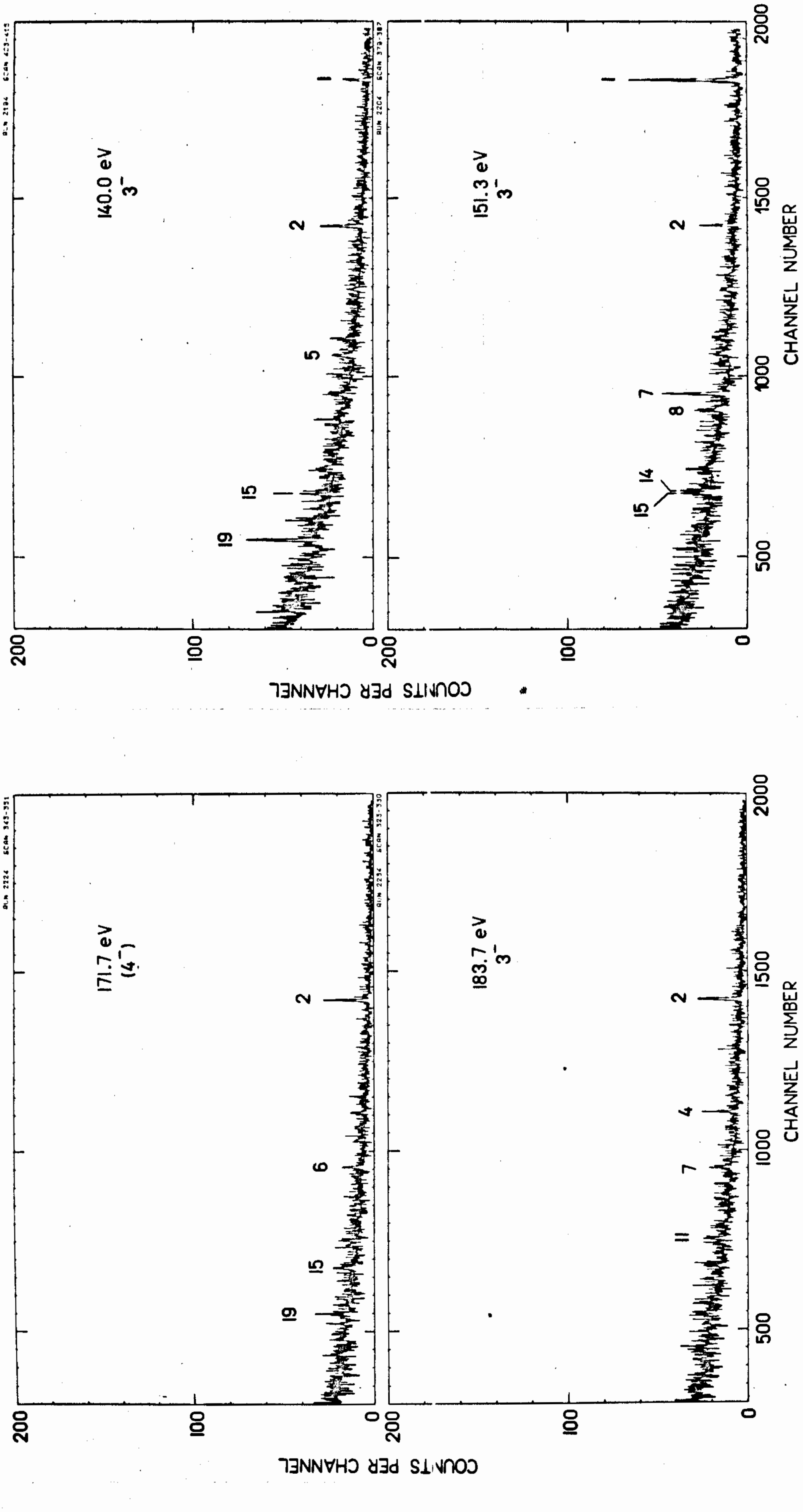
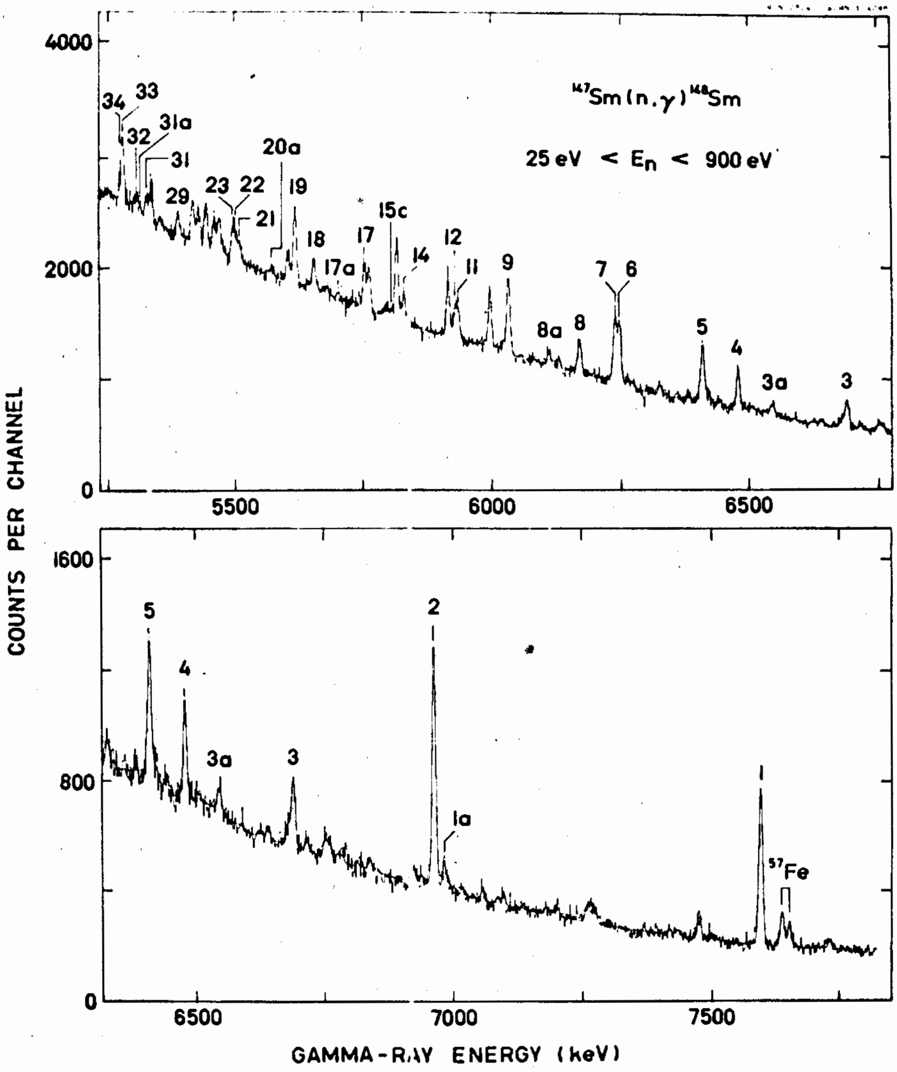
140.0 eV
3⁻
19
15
5
2
151.3 eV
3⁻
15
14
8
7
2
171.7 eV
(4⁻)
19
15
6
2
183.7 eV
3⁻
11
7
4
2
COUNTS PER CHANNEL
CHANNEL NUMBER
0
100
200
500
1000
1500
2000

FIG. 2e



^{147}Sm(n,γ)^{148}Sm
25 eV < E$_n$ < 900 eV
COUNTS PER CHANNEL
GAMMA-RAY ENERGY (keV)
4000
2000
0
1600
800
0
5500
6000
6500
6500
7000
7500
34
33
32
31a
31
29
23
22
21
20a
19
18
17a
17
15c
14
12
11
9
8a
8
7
6
5
4
3a
3
5
4
3a
3
2
1a
1
^{57}Fe

FIG. 3

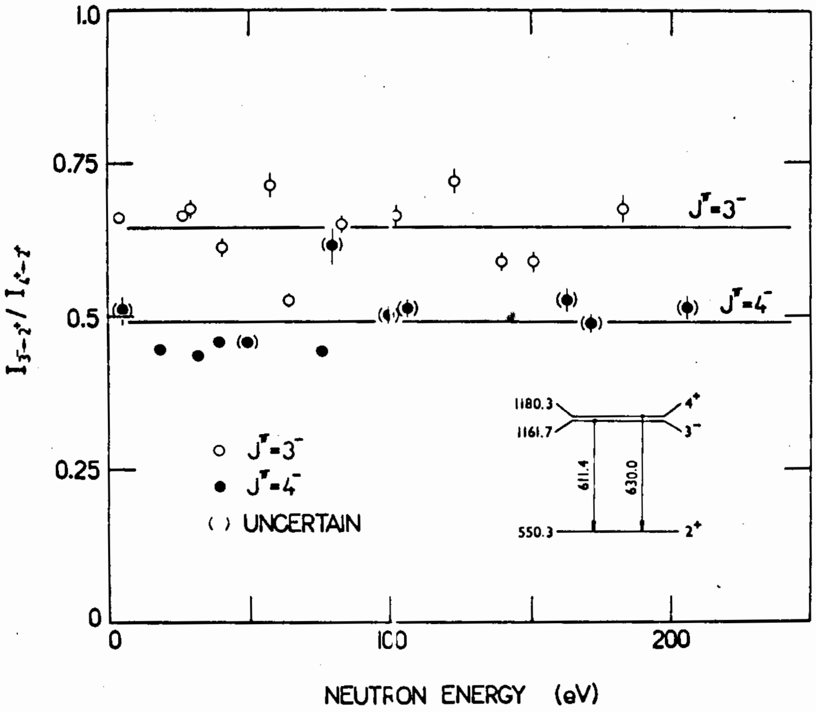
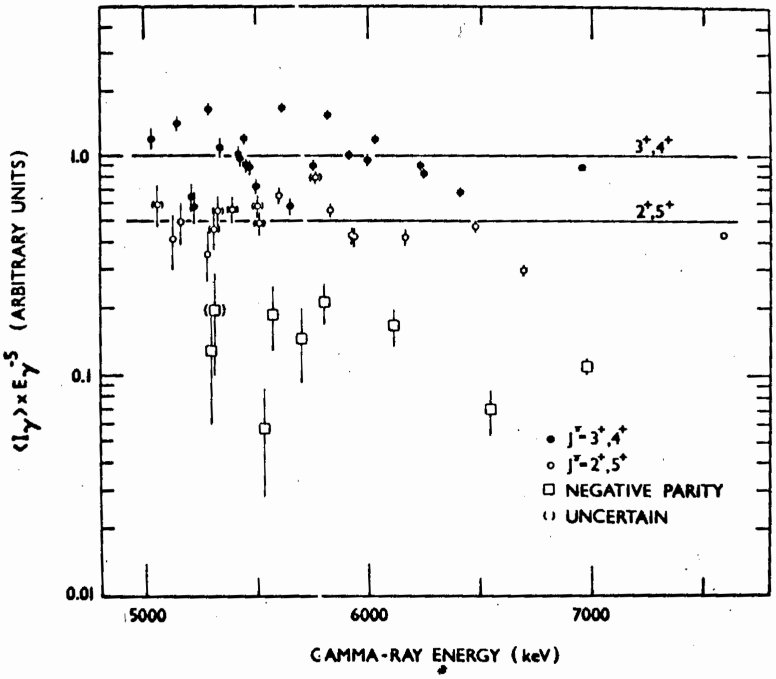
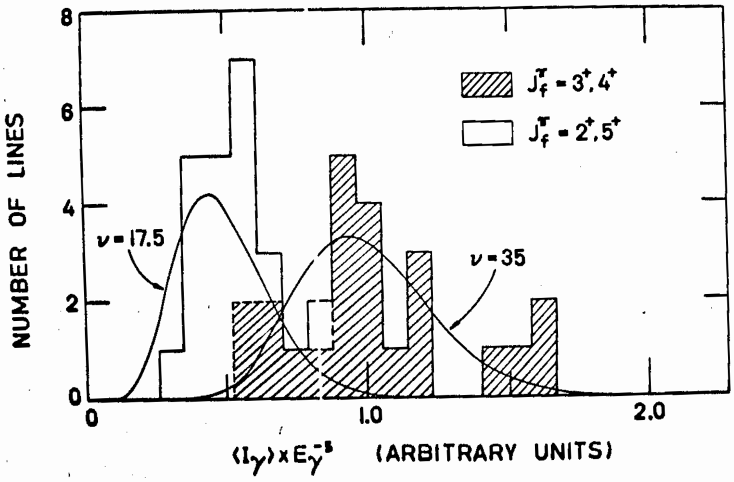

1.0
0.75
0.5
0.25
0
0
100
200
NEUTRON ENERGY (eV)
$I_{3^- \to 2^+} / I_{4^+ \to 2^+}$
$J^\pi = 3^-$
$J^\pi = 4^-$
○ $J^\pi = 3^-$
● $J^\pi = 4^-$
( ) UNCERTAIN
1180.3
1161.7
4^+
3^-
611.4
630.0
550.3
2^+

FIG. 4



1.0
0.1
0.01
5000
6000
7000
$\langle I_\gamma \rangle \times E_\gamma^{-5}$ (ARBITRARY UNITS)
GAMMA-RAY ENERGY (keV)
$3^+,4^+$
$2^+,5^+$
● $J^\pi=3^+,4^+$
○ $J^\pi=2^+,5^+$
☐ NEGATIVE PARITY
( ) UNCERTAIN

FIG. 5



8
6
4
2
0
0
1.0
2.0
NUMBER OF LINES
$\langle I_\gamma \rangle \times E_\gamma^{-5}$ (ARBITRARY UNITS)
▨ $J_f^\pi = 3^+,4^+$
☐ $J_f^\pi = 2^+,5^+$
$\nu = 17.5$
$\nu = 35$

FIG. 6

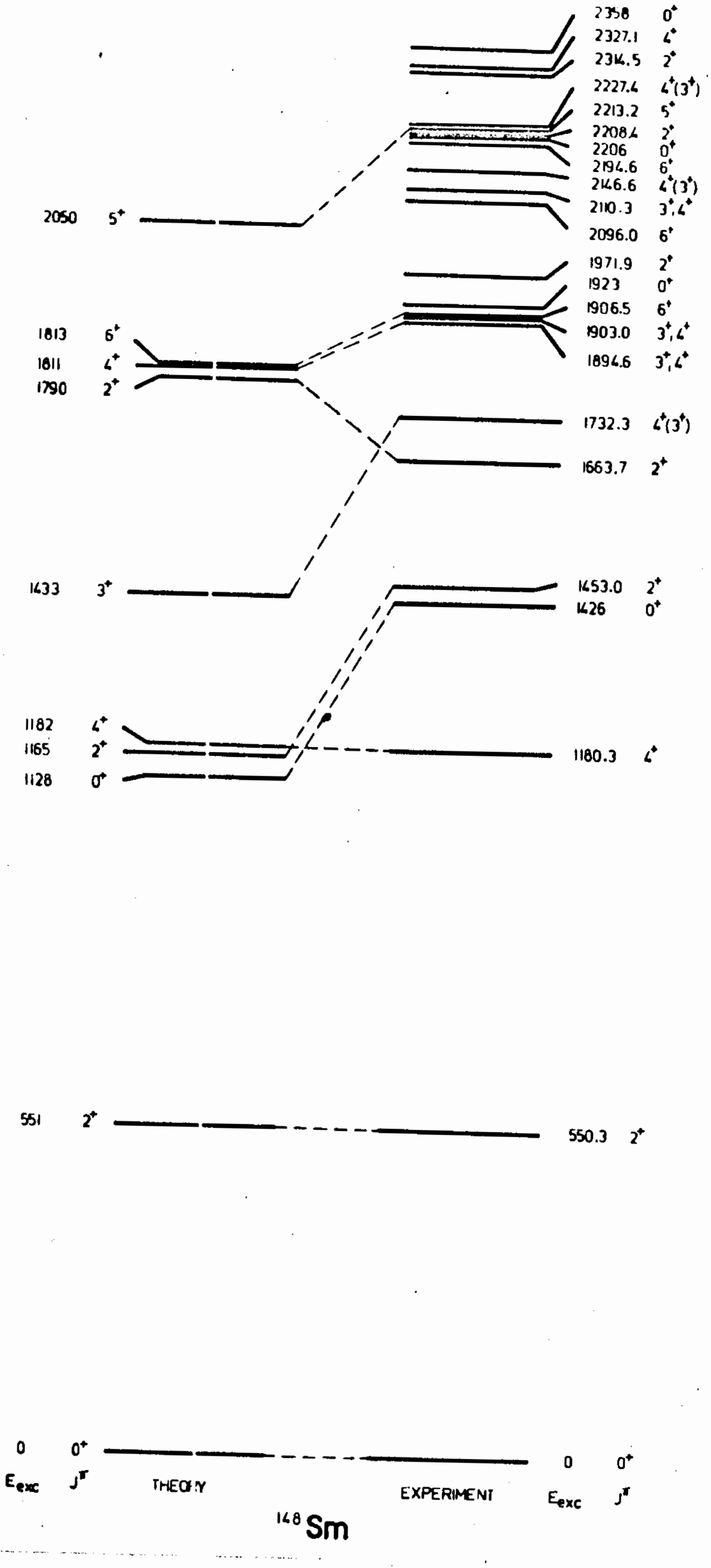

2358 0+
2327.1 4+
2314.5 2+
2227.4 4+(3+)
2213.2 5+
2208.4 2+
2206 0+
2194.6 6+
2146.6 4+(3+)
2110.3 3+,4+
2096.0 6+
1971.9 2+
1923 0+
1906.5 6+
1903.0 3+,4+
1894.6 3+,4+
1732.3 4+(3+)
1663.7 2+
1453.0 2+
1426 0+
1180.3 4+
550.3 2+
0 0+
2050 5+
1813 6+
1811 4+
1790 2+
1433 3+
1182 4+
1165 2+
1128 0+
551 2+
0 0+
Eexc Jπ
THEORY
EXPERIMENT
Eexc Jπ
148Sm

FIG. 7