PROGRESS REPORT

ON

"Radioactive Decay Studies at TRISTAN"

TO

THE DIVISION OF NUCLEAR PHYSICS
U.S. DEPARTMENT OF ENERGY
OFFICE OF HIGH ENERGY AND NUCLEAR PHYSIS

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Submitted by

William B. Walters, Professor of Chemistry, 500-44-7566
Phone (301) 454-4421

Department of Chemistry
University of Maryland
College Park, MD 20742

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I. Introduction

The start of successful operation of the on-line isotope separator TRISTAN at the High Flux Beam Reactor at Brookhaven National Laboratory in July of 1980 has been followed by increasingly successful runs in September, November, December, January and February. The surface ionization source installed in November has been found to yield not only Rb and Cs as expected, but also Ba, Sr, and apparently Pr, Nd and Pm. The efforts of the entire TRISTAN collaboration have focussed on studies of nuclides that have not been easily separated elsewhere in the world whose level structures are consistent with our overall goals. As shown in the abstracts in Section VII the effort has been a group effort and the results described in this report are the consequence of contributions of the many individuals listed on those abstracts.

Particular appreciation is expressed for the strong efforts to make the TRISTAN facility an effective place to work exerted by R. E. Chrien, R. Gill, M. Shmid, H. Liou and Y. Y. Chu, as well as the technical staff including V. Manzella, F. Paffrath, D. McDonald and W. Hoyes, and to this year's in-house user D. S. Brenner.

II. Angular Correlation and Coincidence Studies of the Excited 0^+ States in $^{142,144,146,148}Ce$ Nuclides

A series of studies has been initiated whose overall aim is a full characterization of the collective structure of the even-even Ce nuclides from the closed shell at N=82 through the transition to deformed structure at N=90. The studies on ^{142}La decay to ^{142}Ce involve only a brief remeasurement of the 1389-641 cascade at 180°, 135° and 90° to test our system and ensure that we could reproduce the earlier results for this proposed 0^+-2^+-0^+ cascade.

A multidetector experiment was conducted at mass 144 where $\gamma\gamma$ coincidences were listed on tape for the decay of ^{144}La to levels of ^{144}Ce at 90° and 180° and coincidences at 135° for the 397-keV 2^+ to 0^+ transition were recorded in the MCA channel. A 0^+-2^+-0^+ cascade has been identified involving the 1422.6-keV γ ray and the 397.3-keV 2^+ to 0^+ transition. This γ ray had been previously identified of feeding the 2^+ state by Ikeda <u>et al</u>. (J. Phys. Soc. Japan <u>47</u>, 1389, 1979). An enormous amount of new data has also been obtained for the decay of ^{144}La to levels of ^{144}Ce. For example, we observe 61 γ rays in the coincidence spectrum with the 541-keV 4^+ to 2^+ transition whereas Ikeda <u>et al</u>. placed only a total of 46 γ rays in the whole level scheme and observed only 16 in the 541-keV gate.

Detailed studies of the decay of ^{146}La to the levels of ^{146}Ce have been carried out. These include a general $\gamma\gamma$ coincidence study at the parent port including multi-spectrum studies, a $\gamma\gamma$ coincidence study at the parent port in which a 1/8" Pb plate was utilized in front of the 20% Ge(Li) detector to effect a reduction in the 397-keV γ rays observed to permit a more efficient study of high energy coincidences, and angular correlatin studies at the daughter port in which measurements were taken at 180°, 135° and 90°. A 0^+ state has been identified at 1043 keV that decays by the 785 - 258-keV cascade.

Study of the decay of ^{148}La to levels of ^{148}Ce has also been initiated. Limited $\gamma\gamma$ coincidence data at 180° have been recorded at the parent port along with multispectrum studies to separate 0.64-sec ^{148}Ba γ rays. Coincidence enhancement evidence supports the assignment of 0^+ spin and parity to the level at 770 keV.

In Fig. II-1 we show the low-lying levels of the even-even Ce nuclides from mass 142 through mass 148 and the systematics of the low-lying 0^+ states. For comparison we show comparable data for the even-even Ba and Nd nuclides with $84 \leq N \leq 90$ in Figs. II-2 and II-3.

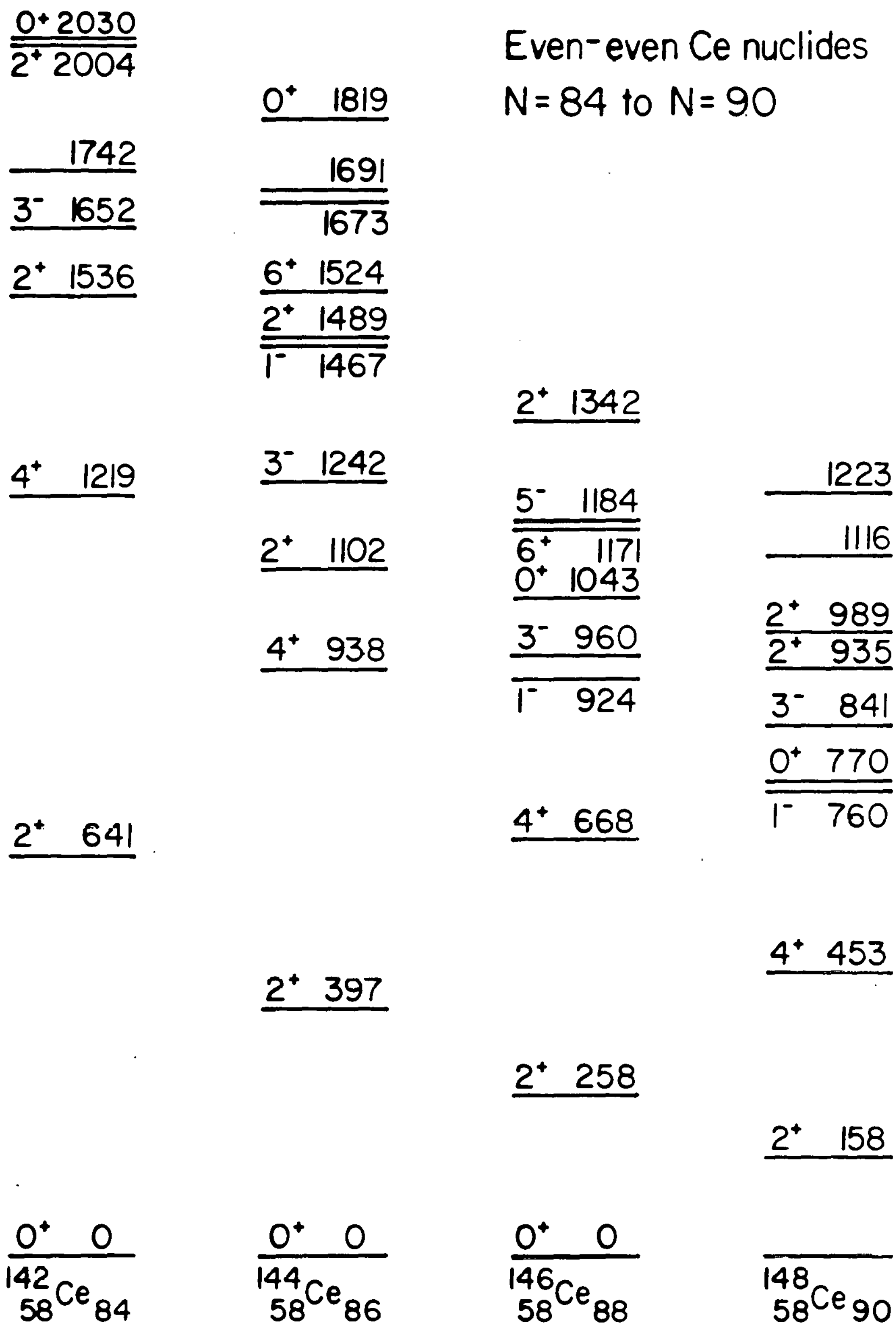


Fig. II-1. The low-lying levels of the even-even Ce nuclides for N=84 to N=90.

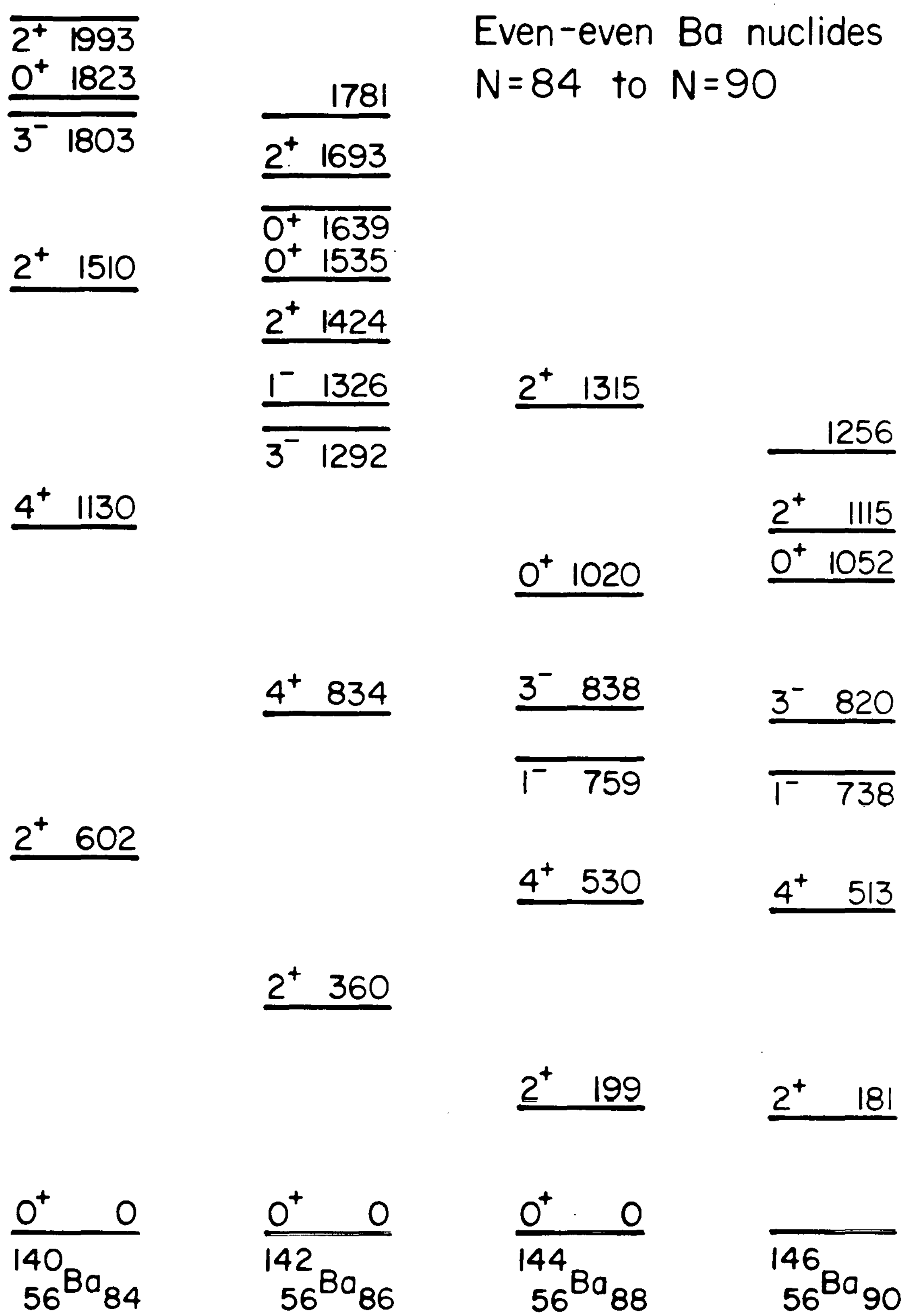


Fig. II-2. The low-lying levels of the even-even Ba nuclides for N=84 to N=90.

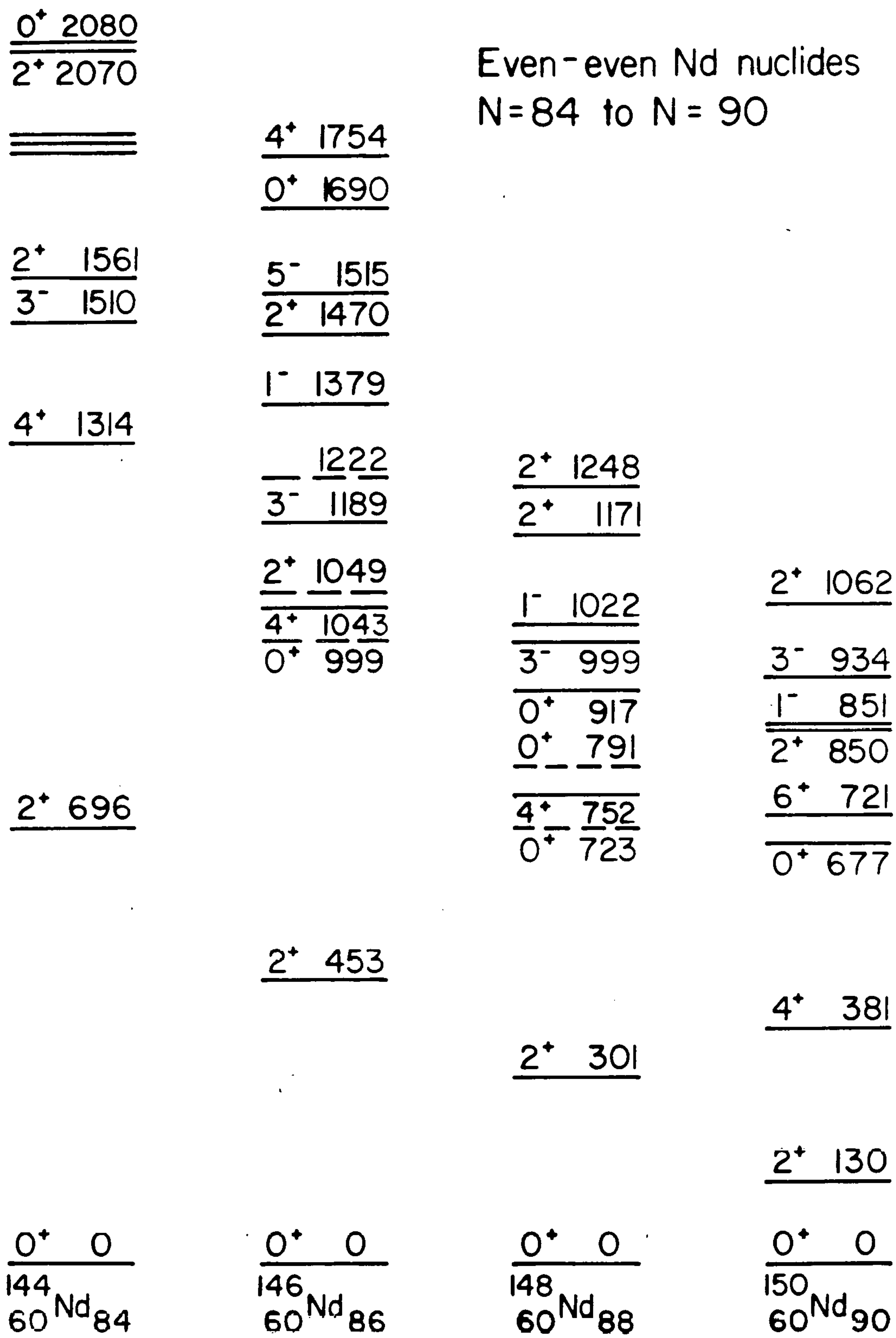


Fig. II-3. The low-lying levels of the even-even Nd nuclides for N=84 to N=90.

III. Study of the Cluster States in the N=85 Nuclides

A study of the levels of the N=85 nuclide ${}^{141}_{56}Ba_{85}$ populated following the decay of ^{141}Cs has been initiated as a precusor to further study of the more neutron-rich Ba nuclides and to the systematics of the N=85 nuclides. The low-lying levels of the N=85 nuclides are shown in Fig. III-1. As is seen, above Z=56, they are characterized by a 3-nucleon cluster of $f_{7/2}$ neutrons coupled to give a $3/2^-$, $5/2^-$, $7/2^-$ triplet. The first result sought in this study is the position and identity of the 3rd level in ^{141}Ba. Initial evidence indicates that there is a level at 55 keV that completes the triplet in ^{141}Ba. Further analysis of the coincidence data is expected to yield a rather complete level scheme as the $7/2^+$ β decay parent can populate a broad range of levels through direct population of 5/2. 7/2, and 9/2 levels and cascades into 1/2, 3/2, 11/2 and 13/2 levels.

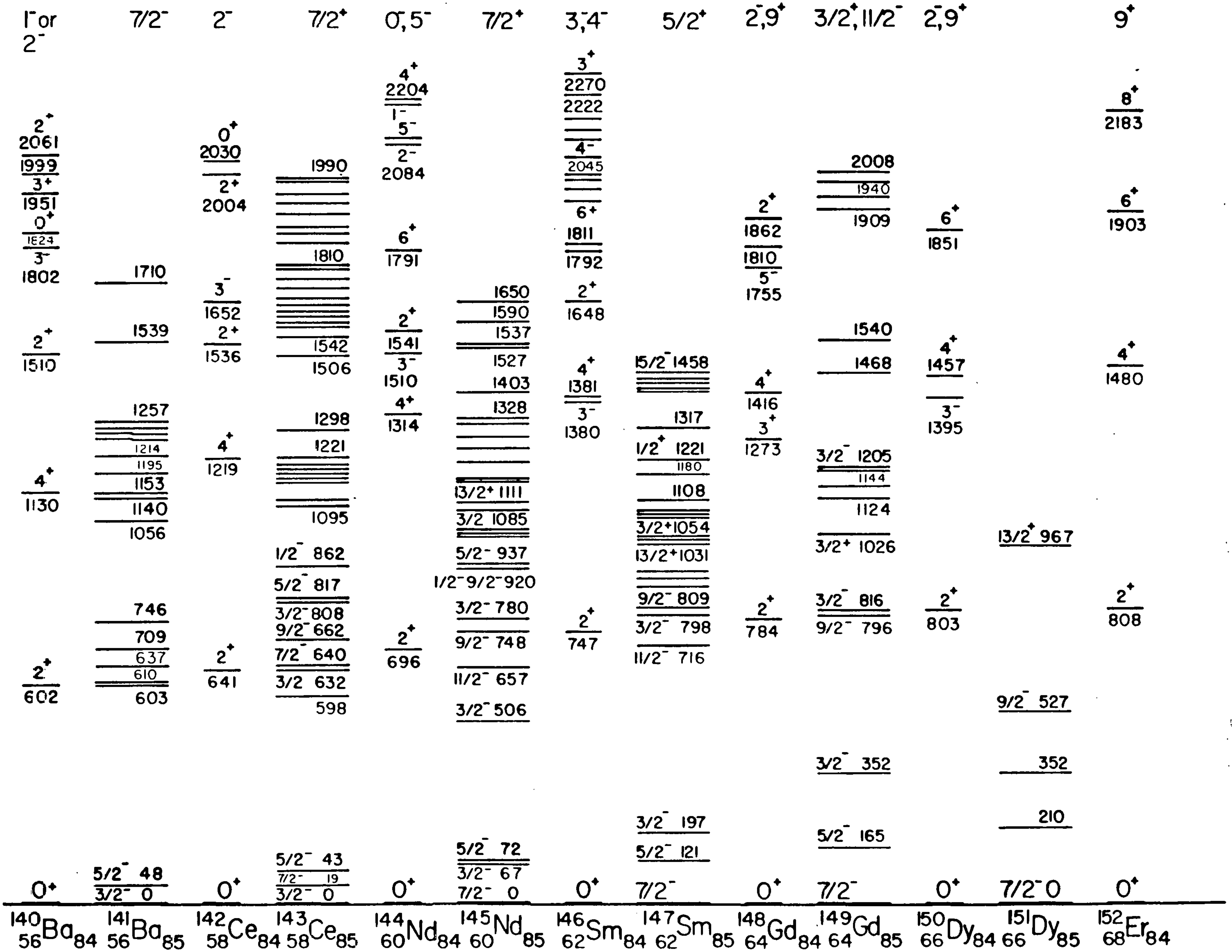


Fig. III-1. Low-lying levels in the N=85 nuclides for Z=56 through Z=66.

IV. Study of Isomerison in ^{148}Pr and the Level Structure of ^{148}Nd

Two recent papers (October, 1979) on the decay of ^{148}Pr report very different conclusions on both the low lying structure of ^{148}Pr and on the position of low-lying 0^+ states in ^{148}Nd. In Fig. IV-1 we show the decay scheme of 2.3-min ^{148}Pr to the levels below 1300 keV in ^{148}Nd proposed by Taylor and Singh (J. Phys. G5, 1445, 1979) and the decay scheme of the 2.27-min and 2.0-min isomers of ^{148}Pr to the levels below 1300 keV in ^{148}Nd proposed by Ikeda et al. (J. Phys. Soc. Japan 47, 1039, 1979).

Several runs have been done on the mass 148 chain at TRISTAN utilizing two different ion sources and several different operating tempertures. If there is only one isomer present, the intensity ratio of 452-keV γ rays to 301-keV γ rays should remain constant as should the intensity ratio of 698- to 721-keV γ rays. If there are two isomers present, the ratios that we observe will depend on whether we see only the low spin isomer fed in from ^{148}Ba decay through the decay of 0^+ ^{148}Ce or whether the ion source is hot enough to be separating Pr directly, thus giving both isomers. Moreover, the ratios we observe could be very different from those observed by Ikeda et al. who isolated Pr directly from mixed fission products and from those measured by Taylor and Singh who studied the products of the $^{150}Nd(d,\alpha)^{148}Nd$ and $^{148}Nd(n,p)^{148}Pr$ reactions. Our data clearly favor the existence of two isomers. We clearly observe more of the 452-and 698-keV γ rays in the runs using the hot plasma source than in the runs using the surface ionization source and much less of these two γ rays than observed by Taylor and Singh. Our coincidence data at this time are not good enough to confirm or propose other placements for the 3 γ rays proposed by the two groups as de-exciting low-lying 0^+ states.

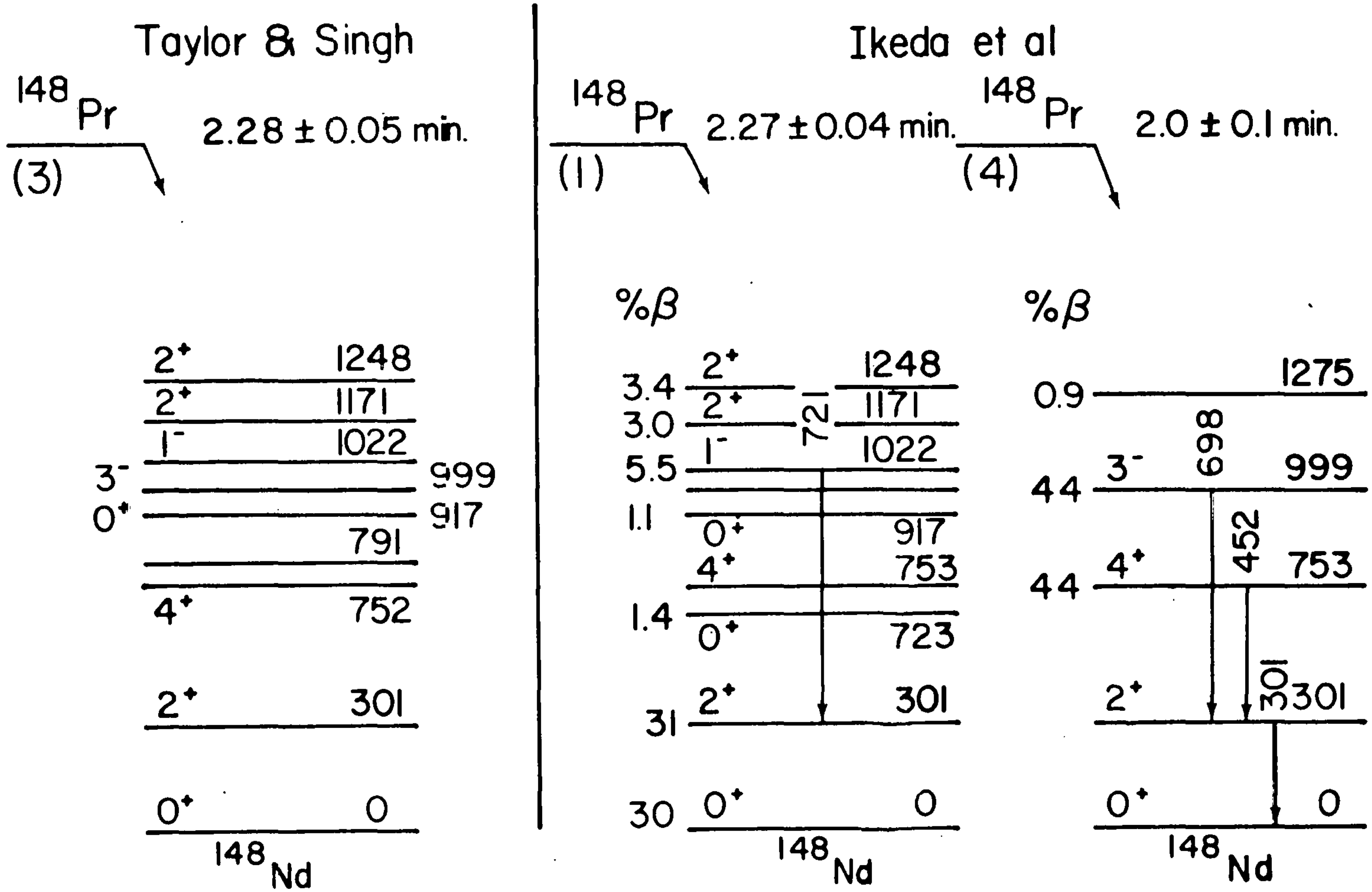


Fig. IV-1. Comparison of the decay schemes of ^{148}Pr by Taylor and Singh and by Ikeca et al.

V. Study of the Levels of ^{148}La Populated in the Decay of 0.64-sec ^{148}Ba

We show in Fig. V-1 a partial, preliminary decay scheme for the decay of 0.64-sec ^{148}Ba to levels on ^{148}La. A lifetime of 90±10 ns has been measured for the 56-keV level and the ratio of K x-rays to 56-keV γ rays is also measured in the number of the coicidence spectra to be ~1. As α_K for a 56-keV E transition is 1.23 and is 6.64 for an M1 transition, the 56-keV γ ray appears to be an E1 transition. The Q_β for this decay is estimated as ~4 MeV and the log f is ~4.0 giving a log ft ≈4. Thus, the β transition to the 56 keV level appears to be strongly allowed and may be assigned 1^+ spin and parity. The ground state spin and parity is thus limited to values of 0^-, 1^-, and 2^-. The observed strong β decay of ^{148}La to 1^- and 3^- levels in ^{148}Ce support a 2^- assignment for ^{148}La.

Even this partial study of ^{148}Ba decay has accomplished two of our major objectives in studying odd-odd nuclides in this region, as we have identified the lowest 1^+ state and also obtained strong evidence for the ground state spin and parity assignment.

It must be noted that this level scheme is quite incomplete. The data were taken in a study primarily aimed at the decay of ^{148}La to levels on ^{148}Ce. Only 2 million total coincidence events were taken in a several day period and most of them are in the La decay to Ce. All of the γ rays shown exhibited a 0.64±0.5 sec half life in the multispectrum study and not a 1.70 sec half life found for ^{148}La decay. Weak crossover transitions to the ground state are notably absent as they did not appear in the coincidence study.

A brief plot of the low-lying levels of the odd-odd La nuclides is shown in Fig. V-2, in which the lowest 1^+ states are shown and the decay paths bearing on the ground state spin and parity are emphasized. A smooth progression is seen for the low-lying 1^+ state is seen and may represent the lowering of energy of the components of the negative parity $h_{11/2}$ proton based Nilsson orbitals that can pair with the components of the negative parity $h_{9/2}$ neutron based Nilsson orbitals.

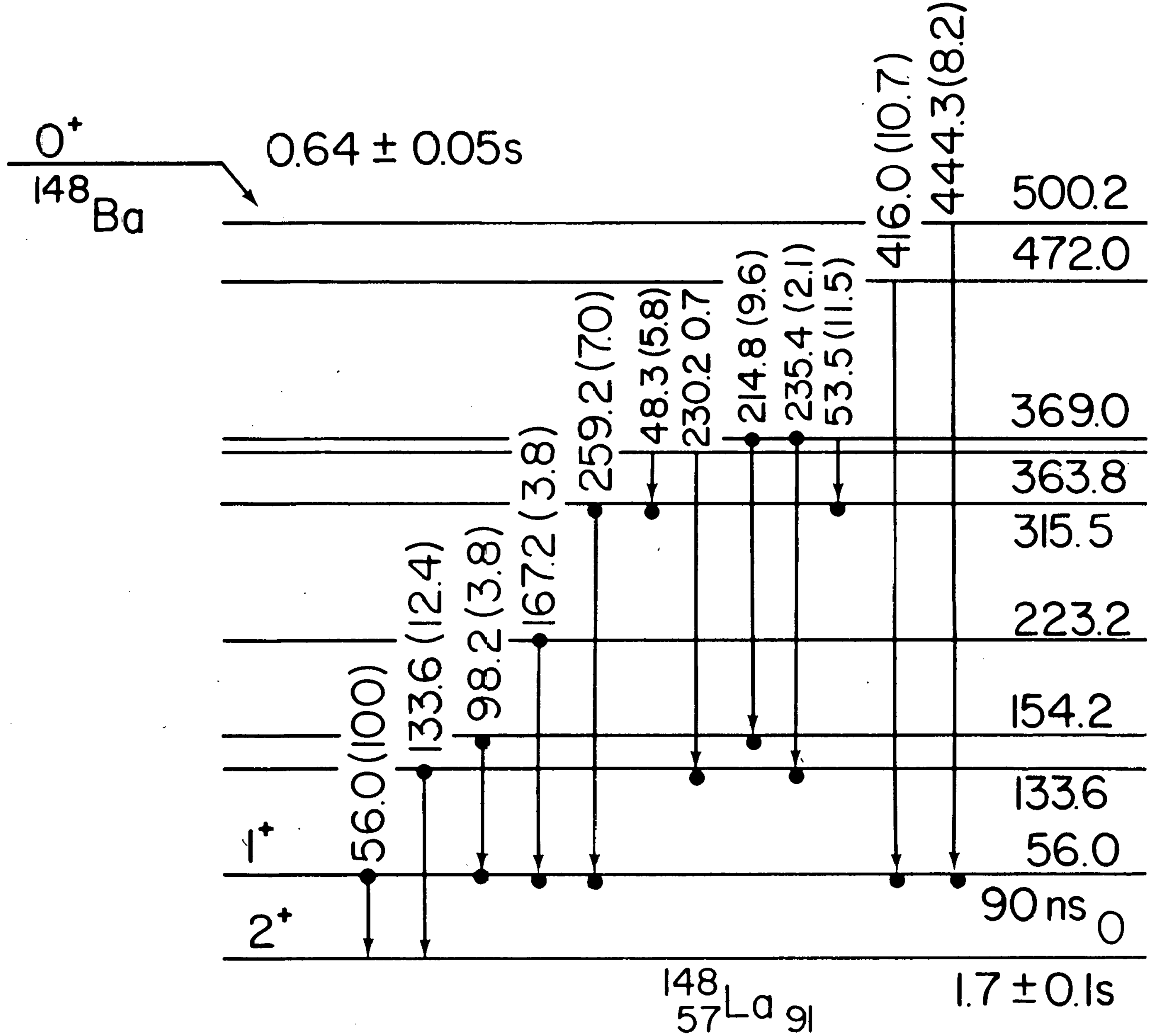


Fig. V-1. Partial, preliminary decay scheme for the decay of 0.64-sec ^{148}Ba to levels of ^{148}La.

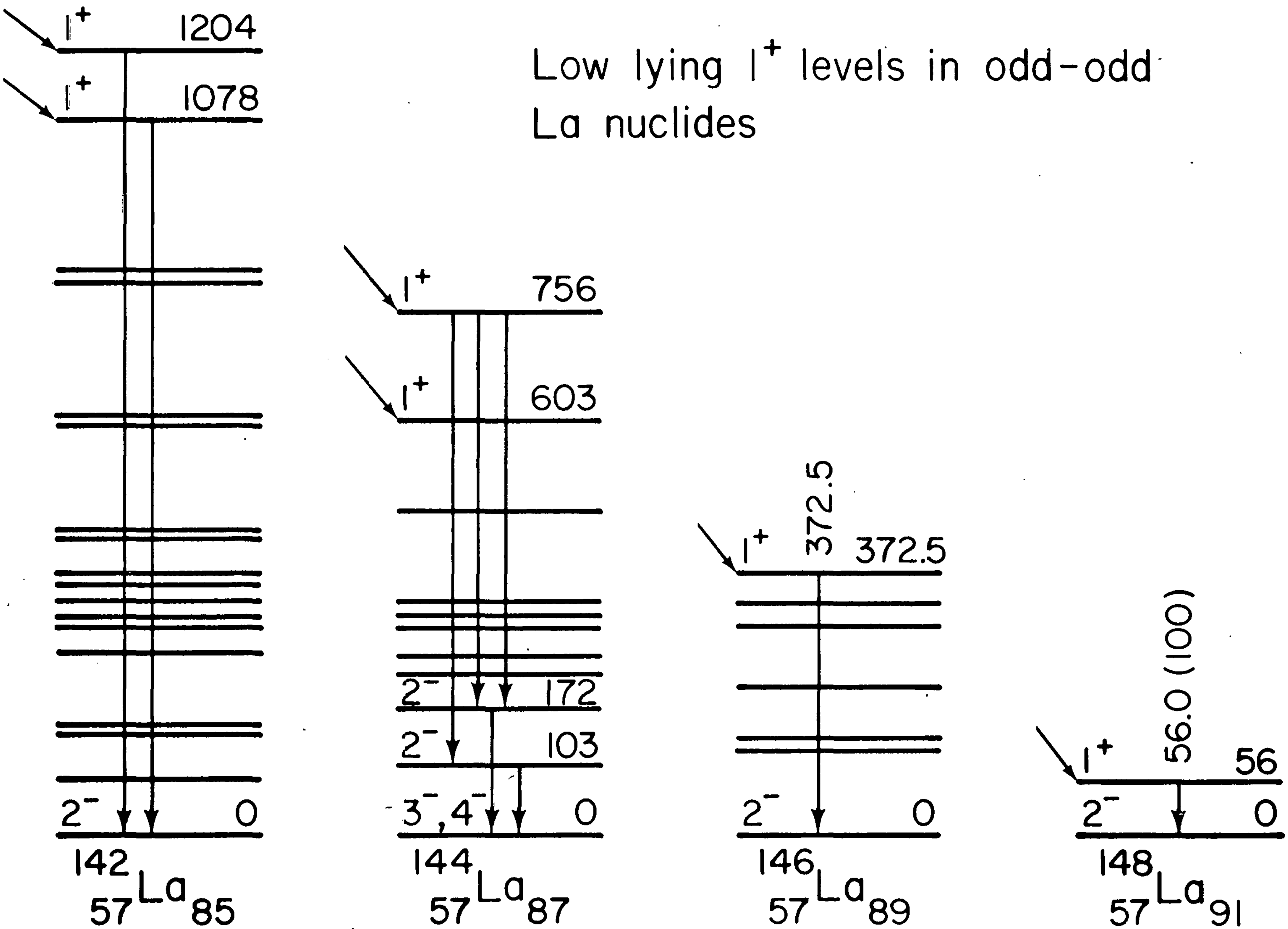


Fig. V-2. Low-lying levels of the odd-odd Z=57 La nuclides for N=85 to N=91.

VI. Facility Development

The development of the multidetector γ-ray coincidence and angular correlation system has moved forward during the year with the addition of a 15% n-type hyperpure Ge detector with an effective energy range beginning at ~14 keV and an effective coincidence range beginning at ~25 keV. This detector has enabled us to carry out lifetime measurements for γ rays and x rays as low as 30 keV and to measure conversion coefficients for low energy γ rays by determining the x-ray/γ-ray ratio in coincidence spectra.

Nearly all of the components for the four-detector setup have been assembled and software changes in the PDP 11/20 data collection system to permit multidetector operation are planned during March and April of 1981. Alterations to the interface are also planned during that period.

A new mechanical arrangement at the daughter port has been built and installed to permit $\gamma\gamma$ coincidence measurements at angles other than 180°. this setup was used for the angular correlation measurements described earlier. Design and construction of flexible collimation and anti-cross talk steel and lead pieces are now underway.

One multidetector angular correlation experiment has been run in which the full coincidence spectrum between two detectors was recorded on tape and the coincidences with a single γ ray in a third detector gated the MCA channel to give a simultaneous spectrum at a second angle for that one γ ray.

Considerable effort is now being given by the BNL group to expanding the flexibility and capacity of the data processing system.

VII. Abstracts Submitted

On the next pages are shown the abstracts submitted for the American Physical Society Meeting in April in Baltimore and the abstracts submitted for the Fourth International Conference on Nuclides Far from Stability to be held in Denmark in June.

Angular Correlation Studies of the Low-Lying 0^+ States in Transitional $^{142-146}$Ce Nuclides.* W. B. WALTERS, C. CHUNG, U. Maryland; F. K. WOHN, K. SISTEMICH, H. YAMAMOTO, Iowa State; D. BRENNER, Clark U.; R. L. GILL, M. SHMID, H. I. LIOU, M. L. STELTS, G. M. GOWDY, Y. Y. CHU, and R. E. CHRIEN, BNL.--Gamma-ray angular correlation studies using a multi-detector coincidence system at the on-line isotope separator TRISTAN, at the High Flux Beam Reactor, Brookhaven National Laboratory, have been performed to map the occurrence of low-lying 0^+ states in ^{142,144,146}Ce nuclides. Our studies confirm a 0^+ assignment for the previously identified state at 2030 keV in ^{142}Ce and establish a new 0^+ state at 1043 keV in ^{146}Ce. Extensive coincidence and angular correlation studies ($\sim 7 \times 10^7$ events) of the decay of 3^- or 4^- ^{144}La were required to determine a 0^+ spin and parity for the 1820 keV level in ^{144}Ce and establish a number of additional ^{144}Ce levels. The systematic variations of the excited 0^+ states in the Ba, Ce, and Nd nuclides will be presented and discussed.

*Supported by US DOE.

Band Structures in ^{148}Ce. R.L. GILL, M. SHMID, R.E. CHRIEN, G.M. GOWDY, H. LIOU, M. L. STELTS, BNL: D.S. BRENNER, Clark U.; K. SISTEMICH, H. YAMAMOTO, F. K. WOHN, Iowa State U.; C. CHUNG, W. B. WALTERS, U. of Maryland; R. F. PETRY, U. of Oklahoma.*--The onset of nuclear deformations in the rare-earth region is well known to occur at N=90 for even-even nuclei with Z larger than 60 (Nd). Recent studies[1] of the heavy Ba-isotopes (Z=56) showed however, that the onset tends to shift to lower neutron numbers for Z<60. In order to reveal the situation for the intermediate Z=58, the neutron-rich Ce isotopes are studied through the decay of their La parents with the ISOL facility TRISTAN at BNL. A detailed level scheme has been established for ^{148}Ce with N=90. The γ-ray de-excitation pattern suggests the grouping of the low-lying levels into ground-state, β and γ bands. In particular, there is evidence for a 0^+ level at 770 keV. The results indicate that the onset of deformation occurs at a higher N for Ce isotopes than for Ba. They are compared with predictions from the Interacting Boson Approximation.

*Work at all institutions supported by DOE.

[1]S.M. Scott et al., J. Phys. G:Nucl. Phys. 5L, 187 (1979).

Low-Lying Levels in the N=85 Isotone ^{141}Ba.*

H. YAMAMOTO, F.K. WOHN, K. SISTEMICH, Iowa State U.; W.B. WALTERS, C. CHUNG, U. of Maryland; R.L. GILL, M. SHMID, G.M. GOWDY, H. LIOU, R.E. CHRIEN, M. L. STELTS, BNL: D.S. BRENNER, Clark U.; R.F. PETRY, U. of Oklahoma.**--The level structure of the N=85 isotones ^{149}Gd, ^{147}Sm and ^{145}Nd is characterized by 7/2$^-$ ground states and low-lying 5/2$^-$ and 3/2$^-$ states. ^{143}Ce has a ground state of 3/2$^-$, a 7/2$^-$ state at 18.4 keV and a (5/2$^-$) state at 56.2 keV.[1] ^{141}Ba has a (3/2$^-$) ground state and a (5/2$^-$) state at 48.5 keV.[2] Systematics of the odd-A N=85 isotones lead one to expect a low-lying 7/2$^-$ state in ^{141}Ba. Low-energy γ and $\gamma\gamma$ data have been obtained for the decay of mass-separated ^{141}Cs obtained with the ISOL facility TRISTAN at BNL. The 20-ns lifetime of the 48.5-keV level has been reconfirmed and results of the coincidence data, currently under analysis, will be presented.

*Submitted by W. B. Walters

**Work at all institutions supported by DOE.

[1]Nuclear Data Sheets 25, 603 (1978).

[2]Nuclear Data Sheets 23, 529 (1978).

Study of the Decay of Even-mass, Neutron-rich Ba Isotopes.*

C. CHUNG, W. B. WALTERS, U. of Maryland; F. WOHN, K. SISTEMICH, H. HAMAMOTO, J. C. HILL, Iowa State; D. BRENNER, Clark U.; Y. Y. CHU, G. M. GOWDY, M. SHMID, R. L. GILL, H. I. LIOU, M. L. STELTS, R. E. CHRIEN, BNL.--The ISOL facility TRISTAN at the BNL HFBR was used to study the decay properties of ^{146}Ba and ^{148}Ba from thermal neutron fission of ^{235}U. Barium isotopes were directly extracted from the surface ionization source and also accumulated from the decay of cesium precursors extracted directly. The 142 keV line reported in ^{148}Cs decay was not observed by us despite some evidence of ^{148}Cs direct extraction at TRISTAN. The level structures of ^{146}La and ^{148}La were investigated by singles, $\gamma\gamma$-coincidence, and time-sequenced singles measurements. The observed half-life of ^{148}Ba, 0.7 sec, is somewhat longer than previously reported. At least 20 γ-lines associated with the ^{148}Ba decay were identified for the first time. The first excited level of ^{148}La, 56 keV, was observed to have a lifetime of about 65 ns. More than 50 new γ-lines were found in ^{146}Ba decay.

*Supported by US DOE.

The Study of the Decays of ^{147}Cs and ^{147}Ba and the Reinvestigation of the Decay of ^{147}La.* Y. Y. CHU, M. SHMID, R. L. GILL, G. M. GOWDY, H. I. LIOU, M. L. STELTS, R. E. CHRIEN, BNL; C. CHUNG, U. of Maryland; D. BRENNER, Clark U.; H. DEJBAKHSH, Oklahoma U.--The decays of ^{147}Cs and ^{147}Ba have been studied using the mass 147 sample collected on-line at TRISTAN facilities. Gamma singles, coincidences and multiscaling measurements have been made. Half-lives of ^{147}Cs and ^{147}Ba were deduced from the γ-multiscaling data and these are to be compared with the literature values. Several γ-rays were assigned to the decay of ^{147}Cs and these confirmed the earlier findings. A large number of γ-rays were assigned to the decay of ^{147}Ba; these have not been reported previously. A tentative decay scheme for ^{147}Ba is proposed based on these results. Measurements were also made on the decay of ^{147}La. The decay scheme deduced from the γ measurements shows more details and is compared with the decay scheme proposed by earlier work.

*Supported by US DOE.

Study of the Decay of Low-Spin ^{148}Pr to Levels in ^{148}Nd.* G. M. GOWDY, R. E. CHRIEN, Y. Y. CHU, R. L. GILL, H. I. LIOU, M. SHMID, M. L. STELTS, BNL; D. S. BRENNER, Clark U.; T. YEH, Cornell U.; K. SISTEMICH, F. K. WOHN, H. YAMAMOTO, Iowa State U.; C. CHUNG, W. B. WALTERS, U. of Maryland; R. PETRY, U. of Oklahoma, R. A. MEYER, LLNL--Recent studies of the decay of ^{148}Pr from sources produced by fast (n,p) reactions and continuous and batch chemical separations from fission products have revealed variations in the relative intensities of a number of γ rays. The presence of two isomers with half lives of 2.27 ± 0.04 min and 2.0 ± 0.1 min has been proposed by Ikeda et al. Studies of mass-separated sources have been carried out at the TRISTAN on-line isotope separator at the BNL High Flux Beam Reactor. These studies provide relative intensities consistent with the low-spin isomeric state of ^{148}Pr as proposed by Ikeda et al. and quite different from those observed in the (n,p) experiments. The level structure of ^{148}Nd is discussed, particularly the states populated in the decay of the low spin ^{148}Pr. The systematics of the even-Nd isotopes are reviewed with emphasis on the behavior of the excited 0^+ states in these nuclei.

*Supported by US DOE.

Decay of the Low-Spin Isomer of ^{146}La to ^{146}Ce.

F.K. WOHN, J.C. HILL, K. SISTEMICH, H. YAMAMOTO, Iowa State U.; D.S. BRENNER, Clark U.; G.M. GOWDY, R.L. GILL, M. SHMID, R.E. CHRIEN, H. LIOU, M. L. STELTS, BNL; W. B. WALTERS, C. CHUNG, U. of Maryland; R.A. MEYER, LLNL,*
--The N=88 nucleus ^{146}Ce lies just below the shape transition around N=90 for rare-earth nuclei. Level structures of ^{146}Ce, as well as ^{148}Pr (N=88) and ^{148}Ce (N=90), are under investigation with the ISOL facility TRISTAN at BNL. For ^{146}La, isomers with 4.5 m and 8.5 s half-lives have been reported.[1] Recent studies with on-line mass separators indicate 6 s and 10 s isomer instead of on 8.5 s isomer.[2] With TRISTAN, ^{146}La is produced primarily by the β decay of even-even ^{146}Ba, thus the low-spin isomer of ^{146}La is produced. The low-energy band structure of ^{146}Ce, including a first-excited 0^+ state, has resulted from detailed γ spectroscopic studies at TRISTAN. Our low-spin isomer results will be combined with results from both short-lived isomers, produced directly from fission, to deduce decay schemes of both isomers and compare ^{146}Ce levels with predictions of IBA model.

*Work at all institutions supported by DOE.
[1]G. Skarnemark et al., J. In. Nucl. Ch. 39, 1487 (1977).
[2]E. Monnand, CENG, Private communication (1980)

Study of the Decay of ^{99}Rb and ^{99}Sr.*

R. PETRY, H. DEJBAKHSH, U. of Oklahoma; C. CHUNG, W. B. WALTERS, U. of Maryland; D. BRENNER, Clark U.; M. SHMID, R. L. GILL, H. I. LIOU, M. L. STELTS, R. E. CHRIEN, Y. Y. CHU, G. M. GOWDY, BNL.
--The extremely neutron-rich isotopes ^{99}Rb and ^{99}Sr have been investigated with the BNL TRISTAN isotope separator. These studies take advantage of the properties of the high temperature surface ionization source and the high beam intensity available at TRISTAN. Preliminary singles, and time-sequenced singles spectra have been recorded, and coincidence counting is in progress. Half lives of 70 and 250 milliseconds for ^{99}Rb and ^{99}Sr are found to be consistent with previously reported values.[1] At least six γ-ray lines associated with ^{99}Rb decay and 12 associated with ^{99}Sr have been found, extending our knowledge of this decay.[2] The level structure of the daughter nuclides, ^{99}Sr and ^{99}Y, will be discussed.

*Supported by US DOE.
[1]G. Engler et al., Phys. Rev. C19, 1948 (1979).
[2]E. Koglin et al., ILL Ann. Report 1978, 51 (1979).

Precision Q-Value Determinations for Neutron-Rich Rubidium and Cesium Isotopes at TRISTAN.* D. S. BRENNER, M. K. MARTEL, A. APRAHAMIAN, Clark U.; R. E. CHRIEN, Y. Y. CHU, R. L. GILL, G. M. GOWDY, H. I. LIOU, M. SHMID, M. L. STELTS, BNL; F. K. WOHN, Iowa State U.; D. REHFIELD, Vanier; C. CHUNG, U. of Maryland.--Precise β-ray endpoint energies for Rb and Cs fission products were measured using an intrinsic-Ge beta detector at the TRISTAN on-line mass separator facility at the High Flux Beam Reactor at Brookhaven National Laboratory. Beta-ray spectra were recorded as singles and in coincidence with γ-rays in a 20% Ge(Li) detector. Calibration of the digitally-stabilized data acquisition system was done using the well known γ-rays of ^{90}Rb. Endpoint energies were determined by Fermi-Kurie analysis. Q-values are compared with those of other experimenters and with predictions of various mass formulae.

*Supported by US DOE.

Initial Operation of TRISTAN at the Brookhaven HFBR.* R. E. CHRIEN, R. L. GILL, M. SHMID, H. I. LIOU, M. L. STELTS, V. MANZELLA, G. GOWDY, BNL; J. C. HILL, F. WOHN, Iowa State U.; W. B. WALTERS, C. CHUNG, U. of Maryland; D. BRENNER, Clark U.; T. R. YEH, Cornell U.--Recently the on-line mass separator TRISTAN has become operational at the Brookhaven High Flux Beam Reactor. The first experiments were done near the end of 1980 and some of the results are presented in detail elsewhere. The capabilities of the separator, and the associated instrumentation and data acquisition system are described. An active user organization, involving university and national laboratory scientists, has provided much of the necessary personnel for bringing the separator to operating status. A comparison to similar ISOL (isotope separator-on-line) facilities located elsewhere is made. The experimental progress is outlined and some of the major achievements enumerated. The projected experimental program for the near future is described.

*Supported by US DOE.

Angular Correlation and Coincidence Studies of the Excited 0^+ States in the Transitional Ce Nuclides ^{142}Ce, ^{144}Ce, ^{146}Ce, and ^{148}Ce

W. B. Walters and C. Chung
University of Maryland
College Park, Maryland 20742 USA

D. S. Brenner
Clark University
Worcester, Massachusetts 01610 USA

R. Gill, M. Shmid, G. Gowdy, M. Stelts, R. Chrien, H, Liou, and Y. Y. Chu
Brookhaven National Laboratory
Upton, New York 11973 USA

F. K. Wohn, K. Sistemich and H. Yamamato
Iowa State University
Ames, Iowa 50011 USA

R. Petry
University of Oklahoma
Norman, Oklahoma 73019 USA

As no single, unified description of nuclear structure exists that offers reliable results for all nuclides, much interest is focussed on nuclides at the edges of regions where good theoretical fits are found. The great success of the rotational description of nuclides with N>90 has stimulated extensive experimental, & theoretical study of the nuclides with $82 \leq N \leq 90$ in various attempts to both observe rotational features below N=90 and to gain an understanding of the nature of the transition from the closed shell at N=82 to the deformed region at N=90. Until recently, the lightest nuclides studies in detail in this region were the Z=60 Nd nuclides and Z=61 Pm nuclides whose structures were consistent with a transition to deformed structures for N=90. The measurement (Ekstrom et al. Phys. Scr. 19, 516, 1979) of a $3/2^+$ ground state for the N=88 nuclide ^{143}Cs has stimulated considerable study of the nuclides with $54 \leq Z \leq 60$ and $82 \leq N \leq 90$ to furthur investigate this transition. In particular Scott, et al. (J. Phys. G. 6, 1291, 1980) have reported studies of the decay of odd-odd Cs nuclides to even-even Ba nuclides and found evidence to support the extension of the deformed region to N=88.

We have utilized the on-line isotope separator TRISTAN at the High-Flux Beam Reactor at Brookhaven National Laboratory to furthur characterize the nuclides with Z<60, $N \leq 92$ to investigate the decay of odd-odd $^{142, 144, 146, 148}$La to levels of even-even $^{142, 144, 146, 148}$Ce. Gamma-gamma coincidence and angular correlation measurements have been utilized in both 2-detector and 3-detector configurations to both establish detailed levels schemes for these nuclides and establish spins and parities for the lower-lying levels.

Our angular correlation data taken at 90°, 135°, and 180° for ^{142}Ce are consistent with the earlier 0^+ assignment for the level at 2030 keV. Extensive new data for the decay of ^{144}La to levels of the N=86 nuclides ^{144}Ce reveal numerous γ rays in coincidence with the 397-keV 2^+ to 0^+ transition (93) and 541-keV 4^+ to 2^+ transition (65). These data suggest a 3^- or 4^- spin and parity for ^{144}La and indicate limited opportunities for populating 0^+ states in ^{144}Nd. The angular correlation data reveal only one 0^+ state at 1819 keV, higher than the 0^+ states at 1535 and 1639 and keV in $^{142}Ba_{86}$ and the 0^+ state at 1687 keV in $^{146}Nd_{88}$

The angular correlation studies on the decay of ^{146}La to levels in the N=88 nuclide ^{146}Ce reveal a 0^+ state at 1043 keV, quite close to the 1020-keV 0^+ state in $^{144}Ba_{88}$, but well above the excited 0^+ state at 911 keV in $^{148}Nd_{88}$.

The $\gamma\gamma$ coincidence studies of the decay of ^{148}La to the N=90 nuclide suggest a 0^+ state at 770.2 keV in ^{148}Ce. This state lies above the excited 0^+ state at 676 keV in $^{150}Nd_{90}$ but far below the excited 0^+ state at 1052 keV in $^{146}Ba_{90}$.

Taken together, these data for the even-even Ba, Ce, and Nd nuclides do not reveal a consistent pattern that can give a clear distinction between deformed nuclides and non-deformed nuclides. While the N=90 nuclides appear to be relatively similar, the rate at which the various states move down from the closed shell at N=82 to the deformed region at N=90 appear variable. In particular, the 1^- and 0^+ states drop sharply between N=88 and N=90 for the Nd and Ce nuclides, but show little change in the Ba nuclides, while 3^- states show the largest change in the Ce nuclides and little change in Ba and Nd.

These data provide an excellent test of any theoretical description of transitional nuclides. The results of the Interacting Boson Model calculations yield relatively good overall fits but detailed comparisions await the resolution of a number of uncertain features of the data.

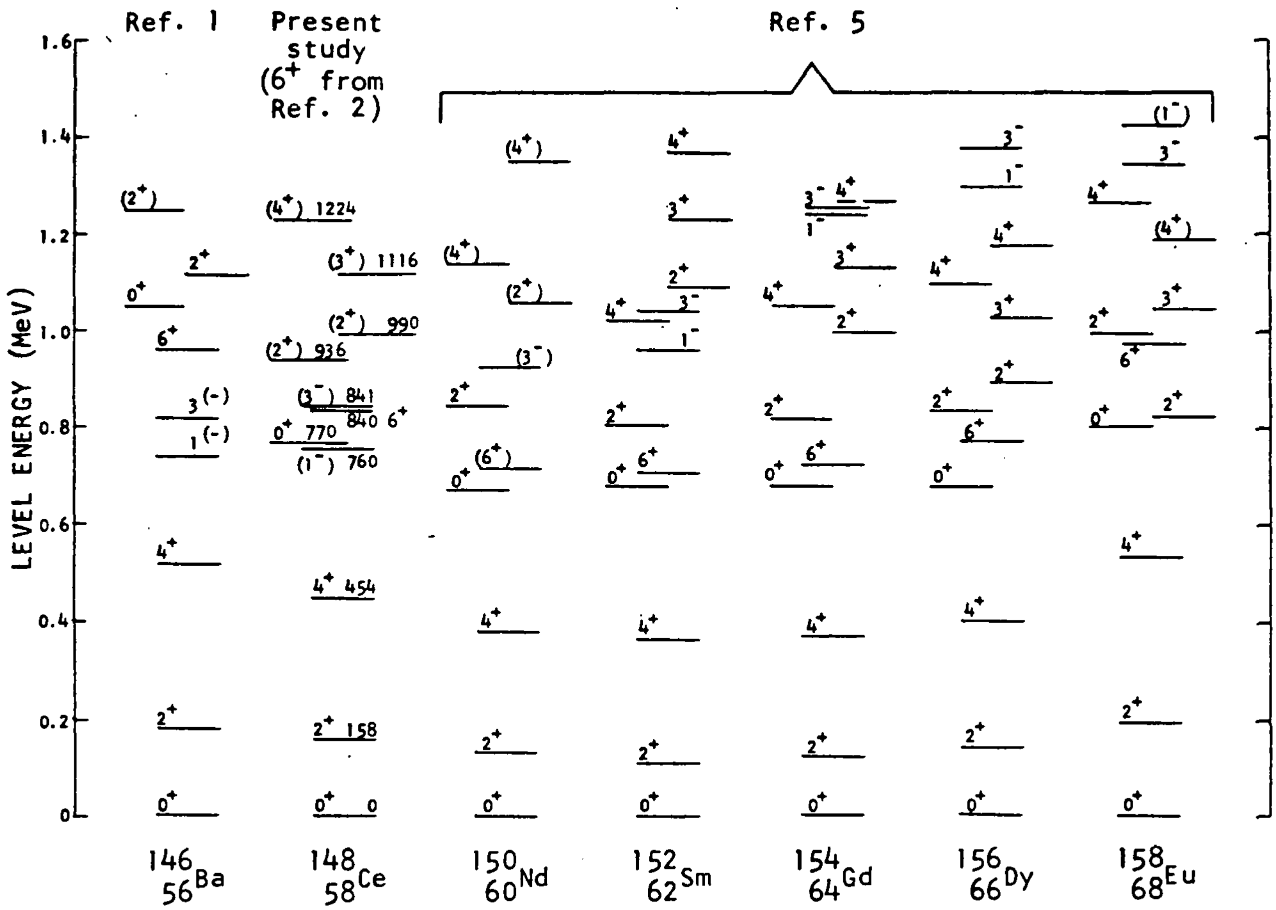
Decays of Mass-Separated ^{148}Ba and ^{148}La*

The TRISTAN Collaboration - D.S. Brenner,[a] R.E. Chrien,[b] C. Chung,[c] R.L. Gill,[b] G.M. Gowdy,[b] J.C. Hill,[d†] H. Liou,[b] R.F. Petry,[e] M. Shmid,[b] K. Sistemich,[d††] W.B. Walters,[c] F.K. Wohn,[d] and H. Yamamoto[d]

The onset of nuclear deformation in the rare-earth region is well known to occur at N=90 for even-even nuclei with Z⩾60 (Nd, Sm, Gd, ···). Recent studies[1] of the heavy Ba isotopes (Z=56) indicate, however, that the onset of deformation tends to shift to lower neutron number with decreasing Z. In order to examine the behavior for the intermediate Ce isotopes (Z=58), neutron-rich ^{148}Ce has been studied with the ISOL facility TRISTAN at the High Flux Beam Reactor at Brookhaven National Laboratory. Detailed γ spectroscopic studies were done for A=148 beginning with the β decay of Ba.

A ^{148}Ce level scheme with 25 levels up to 2250 keV has been established from the decay of ^{148}La, whose half-life was determined by γ-ray measurements to be 1.7 ± 0.2 s. Comparison of the γ-deexcitations with the deexcitation pattern of the other N=90 isotones suggests the grouping of the lowest levels into ground-state, β, and γ bands as shown in the figure, in which tentative J^{π} assignments are in parentheses. (Prior to this work, only 6^+, 4^+, and 2^+ members of the ground-state band had been reported.[2]) In particular, there is strong support for a 0^+ level at 770 keV; this energy is in good agreement with an IBA extrapolation based on fits to higher-Z N=90 isotones.[3] The systematic trends in the energies of the β and γ bands in ^{148}Ce agree well with the other N=90 isotones. In terms of energy ratios and level orderings of the positive parity levels, ^{148}Ce resembles ^{156}Dy more than the other N=90 isotones. The energy ratio of the 0^+_β and 2^+_1 levels is 4.9 for ^{148}Ce, which is similar to that for the other N=90 isotones and is typical for the onset of deformation.[4] The 1^- and 3^- levels also fit well into the systematic trends. The fact that the 1^- level lies

* Work at all institutions supported by the U.S. Department of Energy.
a Clark University, Worchester, MA 01610.
b Brookhaven National Laboratory-USDOE, Upton, NY 11973.
c University of Maryland, College Park, MD 20742.
d Ames Laboratory-USDOE and Iowa State University, Ames, IA 50011.
e University of Oklahoma, Norman, OK 73019.
† On leave of absence to KFA Jülich, Germany.
†† On leave of absence from KFA Jülich, Germany.



below the 3^- level can be interpreted[1] as an indication of stable deformation for ^{148}Ce. Comparison of levels in ^{148}Ce with those in ^{146}Ce shows that the onset of deformation for the Ce isotopes occurs at N=90, as for the higher-Z isotopes, rather than N=88, the apparent onset in the Ba isotopes.

For the ^{148}Ba decay, more than 20 γ rays with a 0.64 ± 0.04 s half-life have been identified. Both γ-ray and neutron[6] measurements yield the same ^{148}Ba half-life. Preliminary analysis of low-energy γ-γ coincidences indicate a life-time of 90 ± 10 ns for the 56-keV first-excited state of ^{148}La. A level scheme for ^{148}La with 16 excited states below 600 keV has been deduced. Prior to this study, no level scheme has been reported.

1. S.M. Scott et al., J. Phys. G: Nucl. Phys. 5L (1979) 187.
2. E. Cheifetz et al., CERN 70-30 (1970) 883; Nucl. Data Sheets 20 (1977) 373.
3. R.F. Casten and D.A. Warner, private communication (1981).
4. M. Sakai, Nucl. Phys. A104 (1967) 301.
5. Table of Isotopes, 7th ed., C.M. Lederer and V.S. Shirley (1978).
6. P.L. Reeder, private communcation (1981).

Study of the Production and Decay of ^{89}Mo Isomers and ^{96}Pd

N. K. Aras, P. W. Gallagher, E. W. Schneider and W. B. Walters
Department of Chemistry and Cyclotron Laboratory,
University of Maryland, College Park, Maryland 20742 USA

We have studied the decay of the new neutron-deficient nuclides, 190 ms ^{89}Mo^{m}, 2.15-min ^{89}Mo^{g}, and 2.0-min ^{96}Pd. The ^{96}Pd was produced in the ^{96}Ru (^{4}He,4n)^{96}Pd reaction using 60-MeV ^{4}He^{++} ions and the ^{89}Mo isomers were produced in the ^{92}Mo(p,p3n)^{89}Mo reaction utilizing 40- to 75-MeV proton beams from the Maryland Cyclotron. The yield patterns showed strong production of the Nb nuclides through the (p,αxn) reactions and only low yields of Tc nuclides from the (p,xn) reactions. At 60 and 75 MeV the 81-,131-, and 171-keV γ rays assigned to 8.2-min ^{88}Mo decay were observed. A half life of 8±1 min could be determined for ^{88}Mo as all three γ rays were parts of multiple peaks. No evidence for the decay of ^{89}Tc was observed in spite of a good knowledge of the important γ rays that would be expected in the decay of either of its isomers.

The low-lying level structure for the N=47 isotones is shown in Fig. 1. These erratic systematic movements seen especially for the $7/2^+$ and $9/2^+$ states may be contrasted with the smooth trends observed for all three states in the Z=47 Ag nuclides. These differences may be related to the very different core changes observed for the underlying Z=46 Pd core and the N=46 core. The Z=46 cores also show smooth changes while the N=46 core reflects the crossing of the Z=40 subshell and the onset of the filling of the $g_{9/2}$ proton orbitals. The E3 transition rates for the $1/2^-$ to $7/2^+$ states show large hindrance factors for both N=Z=47 at low mass with sharply reduced hindrances as the nuclear volume increases.

Our new data for the odd-mass N=48 nuclides also indicates an interesting trend in the particle plus core multiplet that is again very different from those observed in the Z=48 nuclides, but closely related to the N=52 nuclides. These data also indicate the value of attempting further studies of the N=47 and 48 nuclides at higher Z in spite of the difficulties involved.

The level structures observed for the odd-odd N=51 nuclides reflect the strong interactions between the $g_{9/2}$ protons and the single excited $g_{7/2}$ neutron. This strong interaction results in a lowering of approximately 900 keV the 2^+-1^+ splitting in the N=51 odd-odd isotones relative to the $7/2^+$-$5/2^+$ splitting in the adjacent N=51 odd-mass isotone, as is shown in Fig. 2.

Figure 1

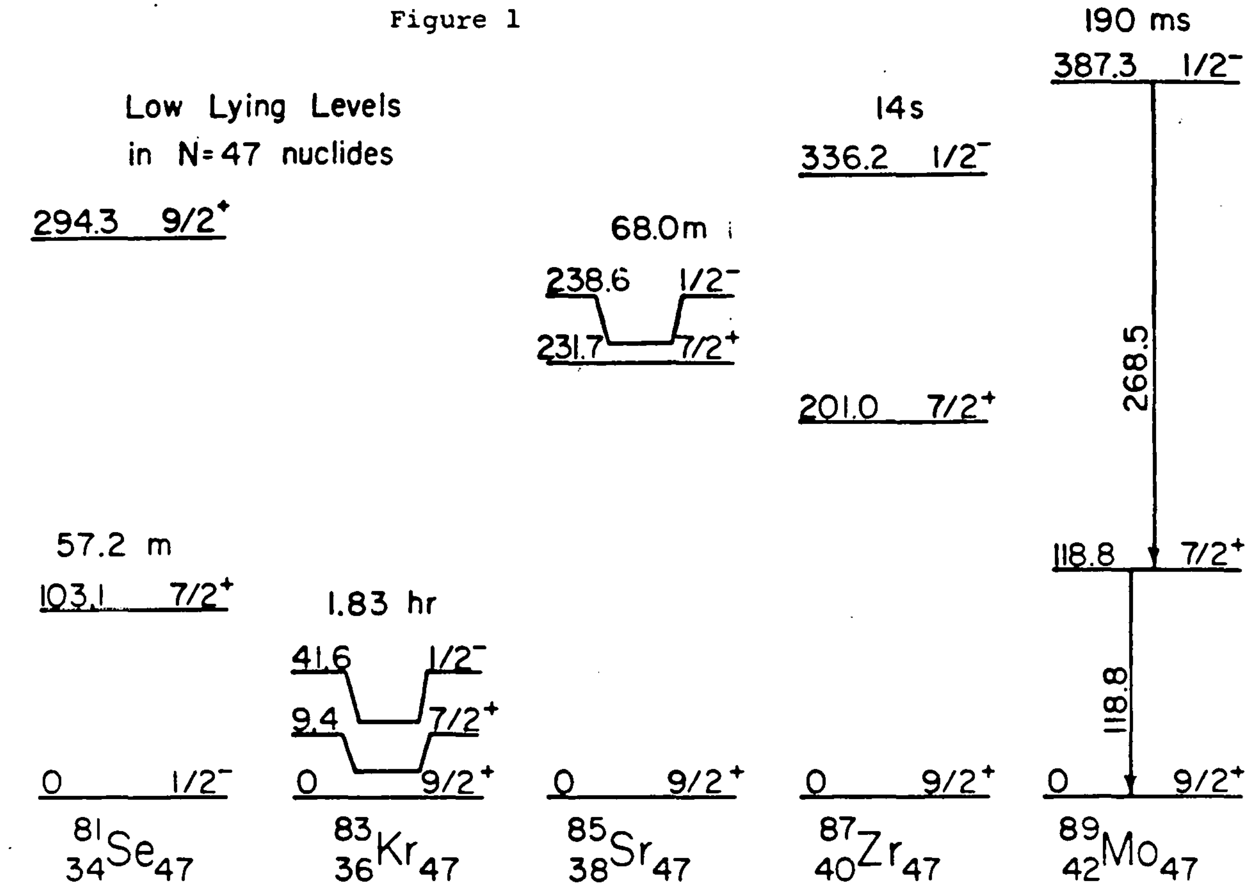
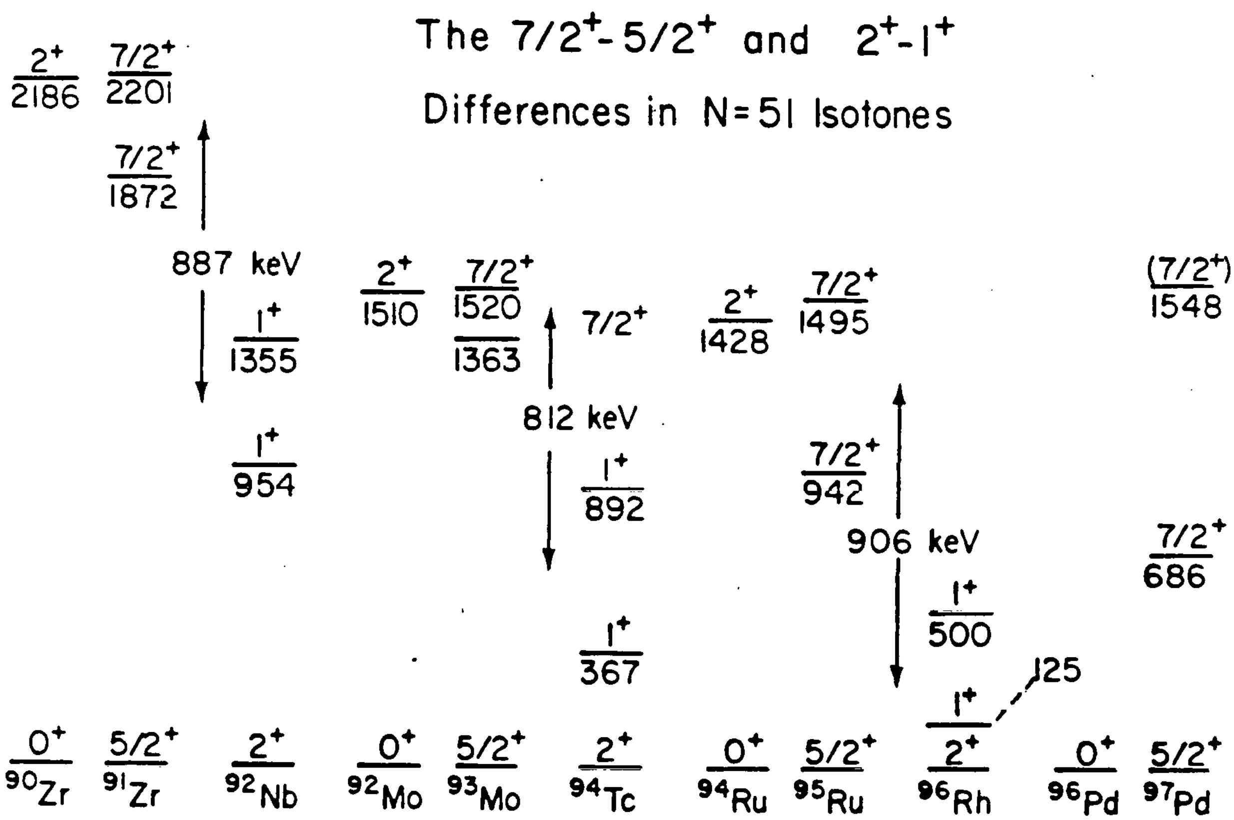


Figure 2



VIII. Personnel, Publications, Presentations and Professional Activities

A. Personnel

Principal Investigator

Dr. W. B. Walters, Professor of Chemistry

Research Associate

Dr. Chien Chung, Research Associate in Chemistry

Visiting Professor

Dr. Namik Aras, on leave from the Middle East Technical University, Ankara, Turkey

Graduate Student

Mr. Scott Faller

Secretary

Mrs. Janet Demech

B. Publications

1. P. W. Gallagher, E. W. Schneider and W. B. Walters, Decay of a New Nuclide: ^{89m}Mo, Z. Physik A296, 81-85 (August, 1980).

2. N. K. Aras, P. W. Gallagher and W. B. Walters, Decay of the New Closed Shell Nuclide 2.0-min ^{96}Pd, J. Phys. G11, L195-L198 (November, 1980).

3. W. B. Walters, "Review of Radiochemistry, Vol. 3", J. Am. Chem. Soc. 102, 7828 (December, 1980).

4. M. Huyse, K. Cornelis, G. Lhersonneau, J. Verplancke, W. B. Walters, K. Heyde, P. Van Isocker, M. Waroquier, G. Wenes and H. Vonex, The Decay of Mass-Separated ^{99g,m}Ag, Nucl. Physics A352, 247 (January, 1981).

5. P. W. Gallagher, N. K. Aras and W. B. Walters, The Decay of ^{89}Mo^{g} to Levels of ^{89}Nb, Phys. Rev. C83, 873-878 (February, 1981).

C. Presentations

1. C. Chung, "Charge Dispersion in Asymmetric and Symmetric Fission", Faculty of Graduate Studies and Research, McGill Univerity, Montreal, Quebec, Canada, March 25, 1980.

2. C. Chung, "Charge Dispersion in Asymmetric and Symmetric Fission", International Summer School on Nuclear Physics, Droenten, The Netherlands, August 21, 1980.

3. C. Chung and J. J. Hogan, "An Interpretation of Symmetric vs. Asymmetric Fission", Proc. of the Int. Conf. on Nuclear Physics, p. 296 (IUPAP, Berkeley, 1980).

4. C. Chung and J. J. Hogan, "Charge Dispersion in Asymmetric and Symmetric Fission", paper NUCL-173, ACS/CSJ Chemical Congress (Las Vegas, 1980).

5. W. B. Walters, The Discovery of the New Nuclides $^{89}Mo^{m}$ and ^{96}Pd at the Maryland Cyclotron, Clark University, Worcester, MA, April, 1980.

6. W. B. Walters, The Study of the Decay of the New Nuclides, $^{89}Mo^{m}$, $^{89}Mo^{g}$, and ^{96}Pd, Iowa State University, Ames, IA, June, 1980.

7. N. K. Aras, P. W. Gallagher and W. B. Walters, Decay of the New Closed Shell Nuclide 2.0-min ^{96}Pd, Second Chemical Congress of the North American Continent, Las Vegas, NV, August, 1980.

8. P. W. Gallagher, N. K. Aras and W. B. Walters, Studies of the Decay of ^{89}Mo Isomers, Second Chemical Congress of the North American Continent, Las Vegas, NV, August, 1980.

D. Professional Activities

Dr. Chien Chung has been selected to receive the Carl A. Winkler Award for presenting the Outstanding Thesis in Science at McGill University in 1980. He was also selected for a tuition and fees scholarship for participation in the Netherlands Summer School of Nuclear Physics held in Droenten in August 1980.

Prof. Walters has been elected to the Executive Committee of the TRISTAN Users Group, and has been appointed Chairman of a new Committee on Education and Professional Training for the ACS Division of Nuclear Chemistry and Technology.

IX. Other Studies of Fission Product Nuclides

Two papers have been in the process of preparation in collaboration with several members of the Nuclear Chemistry Division of the Lawrence Livermore National Laboratory. The work prepared as UCRL-85265 entitled "Shell Model Description of N=81 Five Exciton ^{135}Xe and the Decay of ^{135}I" by W. B. Walters, S. M. Lane, N. L. Smith, R. J. Nagle and R. A. Meyer reports on the results of a detailed experimental and theoretical study of ^{135}Xe levels. The concluding paragraphs are listed below and the results shown in Fig. IX-1.

"An important factor when testing the results of model calculations lies in having observed all or nearly all of the states. A detailed study of $7/2^+$ ^{135}I decay will detect levels populated in allowed or first forbidden decay. Thus, we should observe all $5/2^+$, $7/2^+$ and $9/2^+$ states below 2.5 MeV as well as nearly all $5/2^-$, $7/2^-$ and $9/2^-$ states below that energy. Besides the three low-lying single particle states, (G. S., 308- and 334-keV levels with J^π of $3/2^+$, $1/2^+$ and $11/2^-$, respectively) we observe 28 levels. These include 3 levels which are fed indirectly with J^π values of (energy of level in keV in parenthesis): $1/2^+$ (1543), $3/2^+$ (1448), and $11/2^+$ (1781). The remaining 25 levels that are populated by direct β-feeding can be accounted for by the six $5/2^+$ levels, seven $7/2^+$ levels, and four $9/2^+$ levels whose energy and properties are derived from the calculation, and eight negative parity levels arising from the coupling of the $h_{11/2}$ neutron hole state to the active protons (two $5/2^-$, three $7/2^-$ and two $9/2^-$). In view of the configurational mixing in the wave functions, we expect all $1/2^+$, $3/2^+$, $5/2^+$, $7/2^+$ and $5/2^-$ levels to feed the $3/2^+$ ground state. Hence, we should expect a total of 17 transitions to the ground state and we observe 16. In addition we observe two high energy γ-rays near 2.5 MeV that most likely feed the ground state. We would also expect all $9/2^+$ (4), $7/2^-$ (3) and $9/2^-$ (3) levels and the $11/2^+$

level to feed the $h_{11/2}^{-1}$ state at 526 keV. Here we observe exactly 11 γ rays populating the 11/2⁻ isomer.

Thus, the very large shell model calculation appears to provide an accurate description of the level structure of ^{135}Xe. It would clearly be of interest to be able to determine the calculatd negative parity structure as well as the expected high spin structure. With the current installation of the next generation code on computers such as the CRAY such calculations should be possible."

A second work describing the decay of 11/2⁻ 50-min ^{133}Te^{m} to high spin levels in ^{133}I is being prepared. In that study γ-ray cascades populating 15/2⁻, 17/2⁻, and 19/2⁻ levels are observed. A 9-s 19/2⁻ isomer has been confirmed at 1634 keV in ^{133}I and a 170-ns 15/2⁻ isomer is also indicated at 1729 keV. This study underscores the important of non-statistical factors such as nuclear structure in influencing γ-ray cascades in nuclei. The low-lying level scheme is shown in Figs. IX-2 and IX-3.

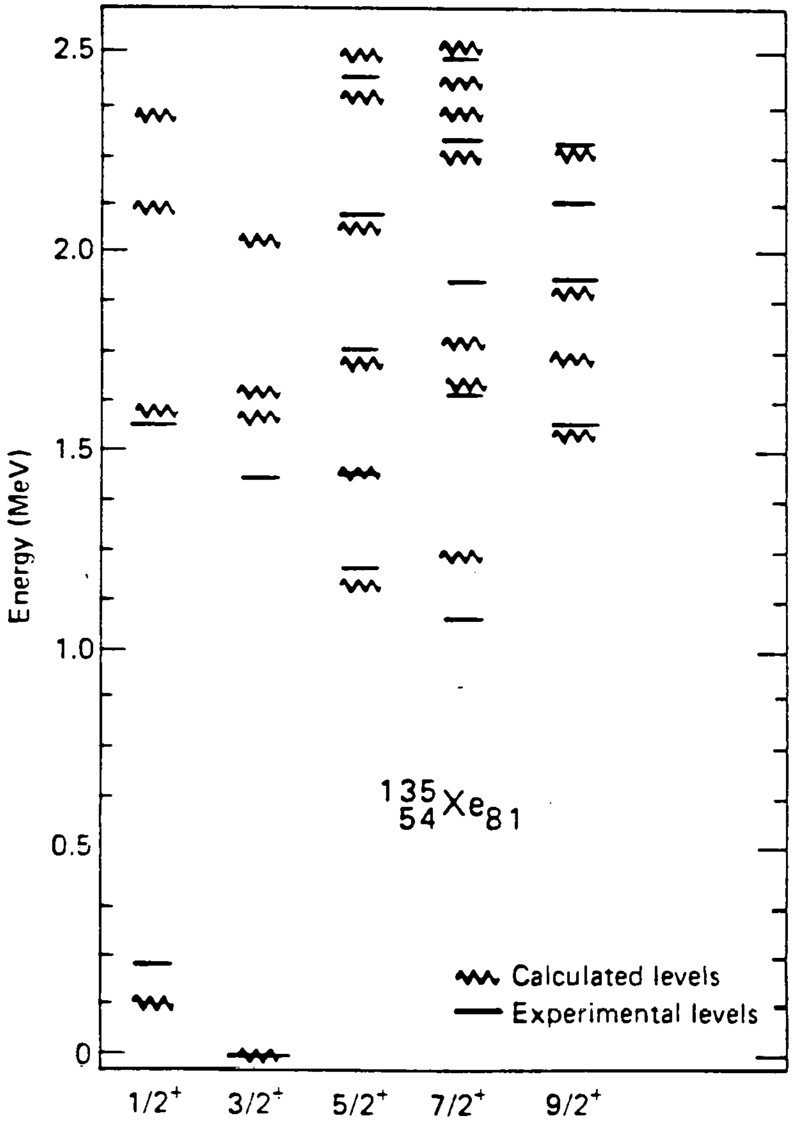


Fig. IX-1. Comparison of the calculated positions of the low-lying positive parity levels on ^{135}Xe with the levels observed following ^{135}I decay.

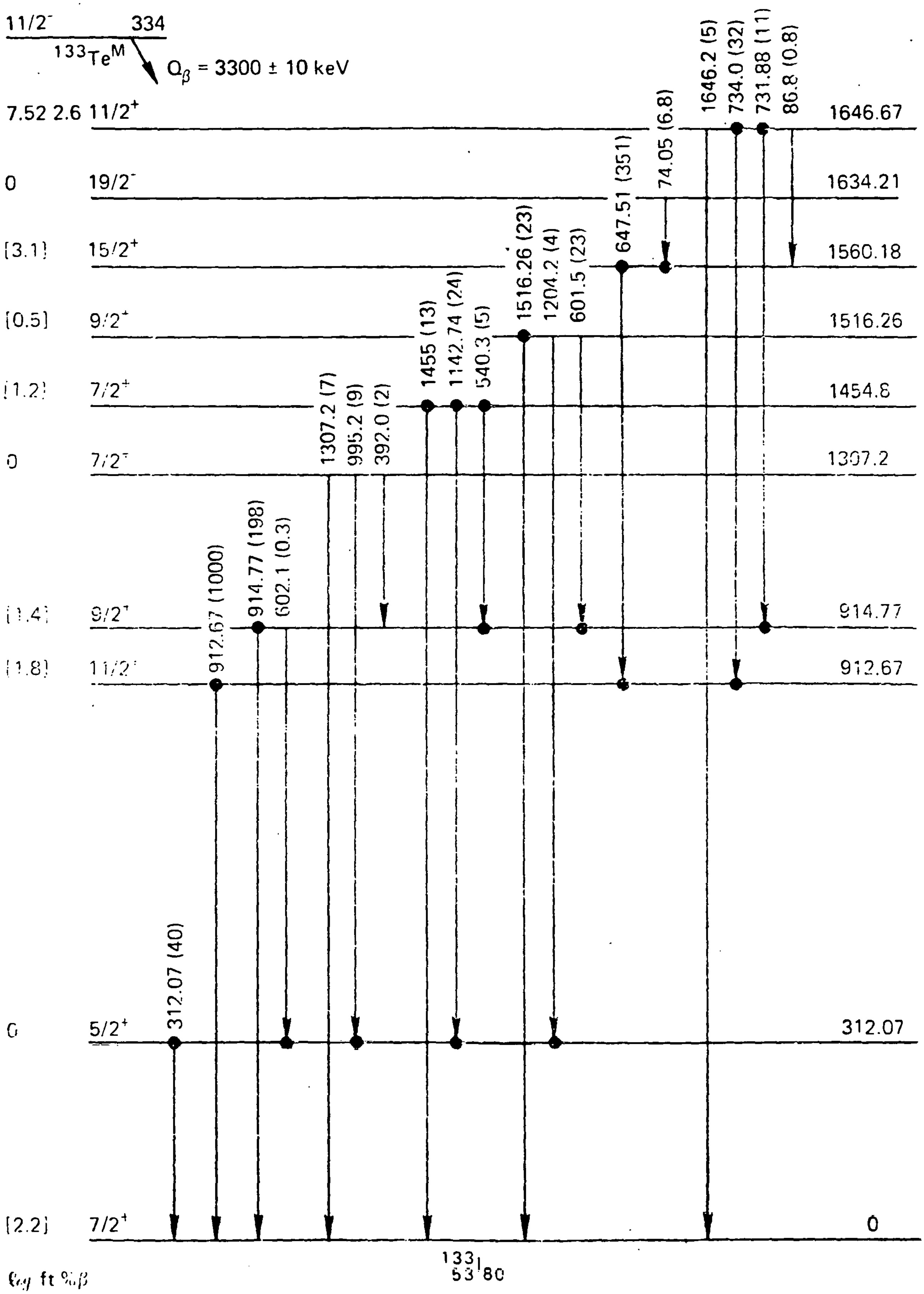


Fig. IX-2. Low-lying levels of ^{133}I populated in the decay of 50-min ^{133}Te^{m}.

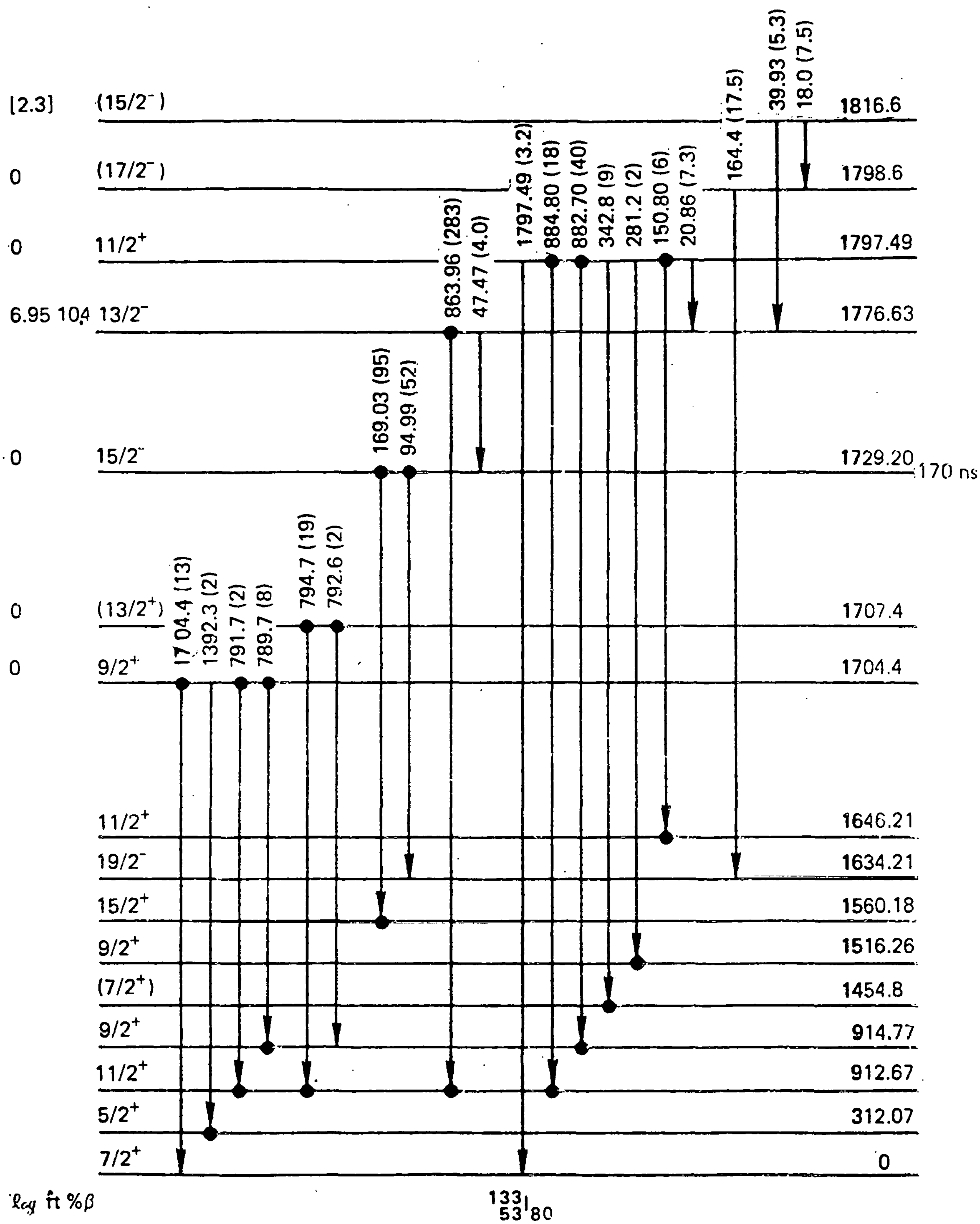


Fig. IX-3. Low-lying levels of ^{133}I populated in the decay of 50-min ^{133}Te^{m}.

X. Other Studies of Neutron Deficient Nuclides

The year 1980 marked the end of support for and operation of the Maryland Cyclotron. Three papers reporting the results of the study of the decay of neutron deficient nuclides have been published during the past year and are listed in Section VIII. Two new isomers of ^{89}Mo were identified and their decay schemes measured, and the closed shell nuclide ^{96}Pd was identified and its decay to levels of ^{96}Rh investigated. The results of the study of 190-ms ^{89}Mo^{m} reveal an erratic trend in the systematics of the low-lying $1/2^-$, $7/2^-$ and $9/2^-$ levels in N=47 nuclides as shown in Fig. X-1. The hindrance factors for the E3 isomeric transitions in the N=47 isotones are also shown in Fig. X-2 to vary in a manner similar to those observed in the Z=47 Ag nuclides in spite of the very different core behavior.

The two 1^+ levels identified in ^{96}Rh following the decay of 2.15-mm ^{96}Pd also establish the existence of a strong lowering of the $(\pi g_{9/2}\ \nu g_{7/2})_{1^+}$ state relative to the $(\pi g_{9/2}\ \nu d_{5/2})_{2^+}$ state in the N=51 isotones. The 2^+ and 1^+ energy levels are shown in Fig. X-3 and their differences compared with the $5/2^+$ to $7/2^+$ differences in the adjacent N-51 odd-mass isotones.

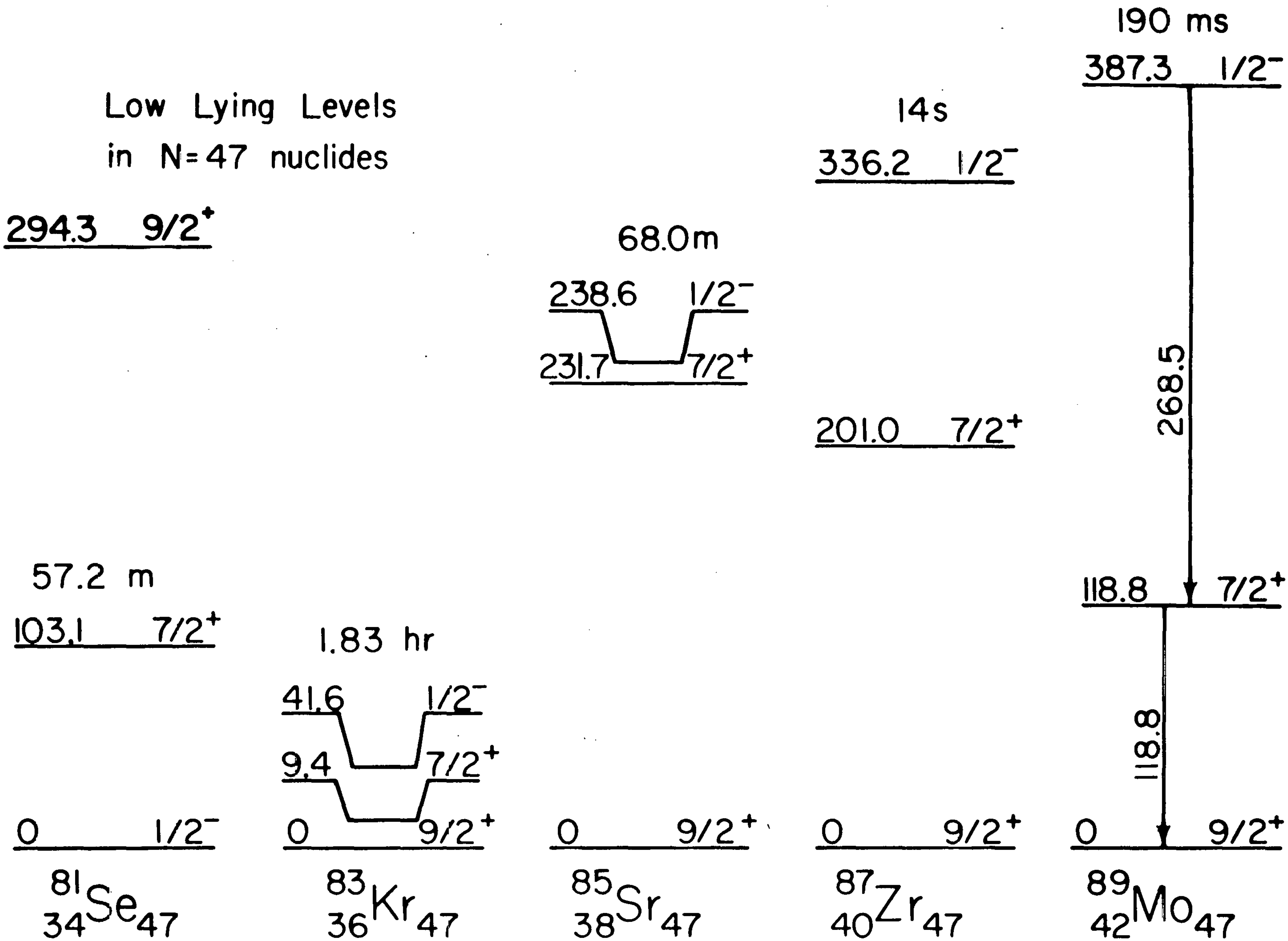


Fig. X-1. The low-lying $9/2^+$, $7/2^+$ and $1/2^-$ levels in N=47 isotones.

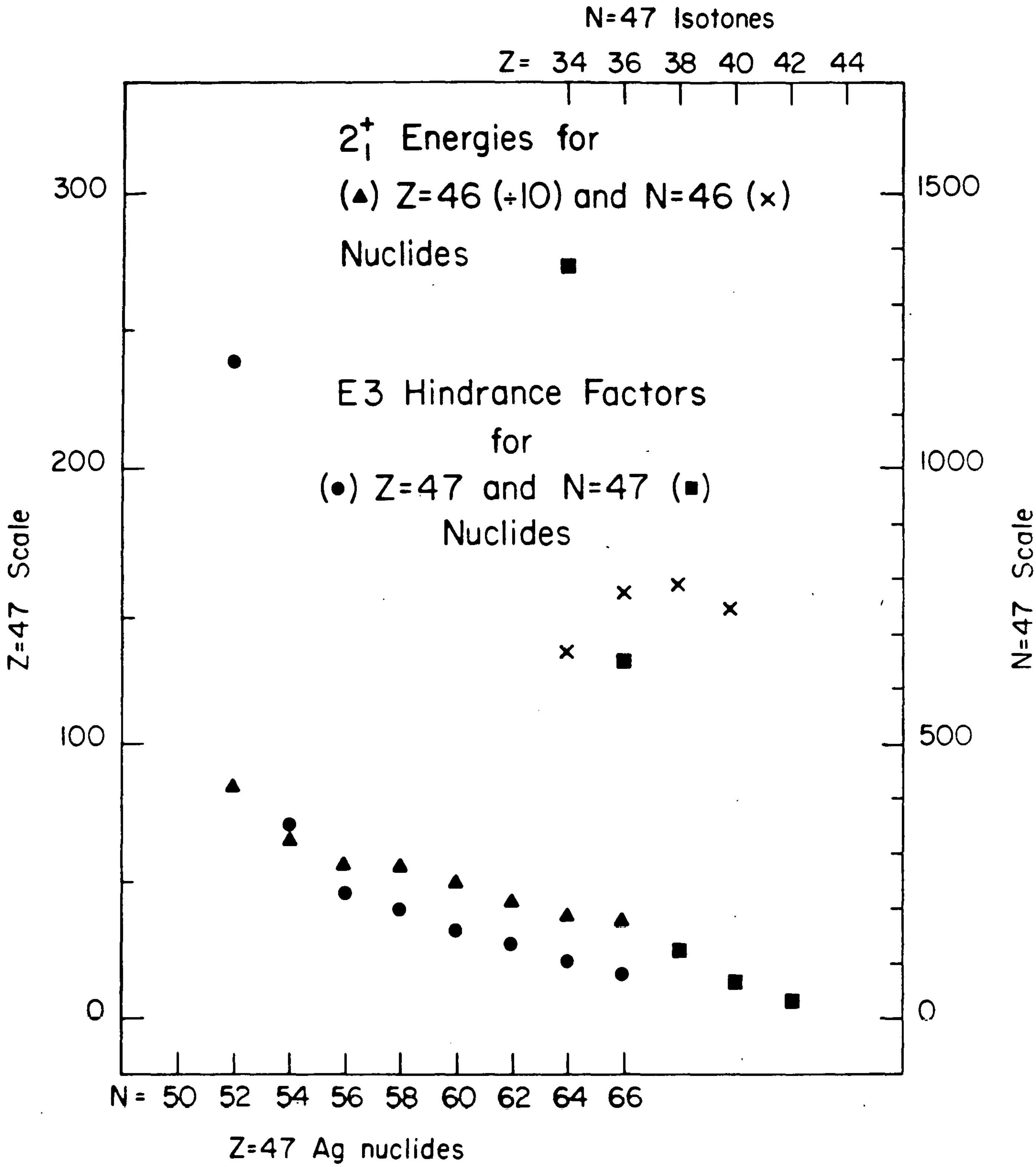


Fig. X-2. The E3 hindrance factors and core 2^+ energies for the N=47 isotones and Z=47 isotopes.

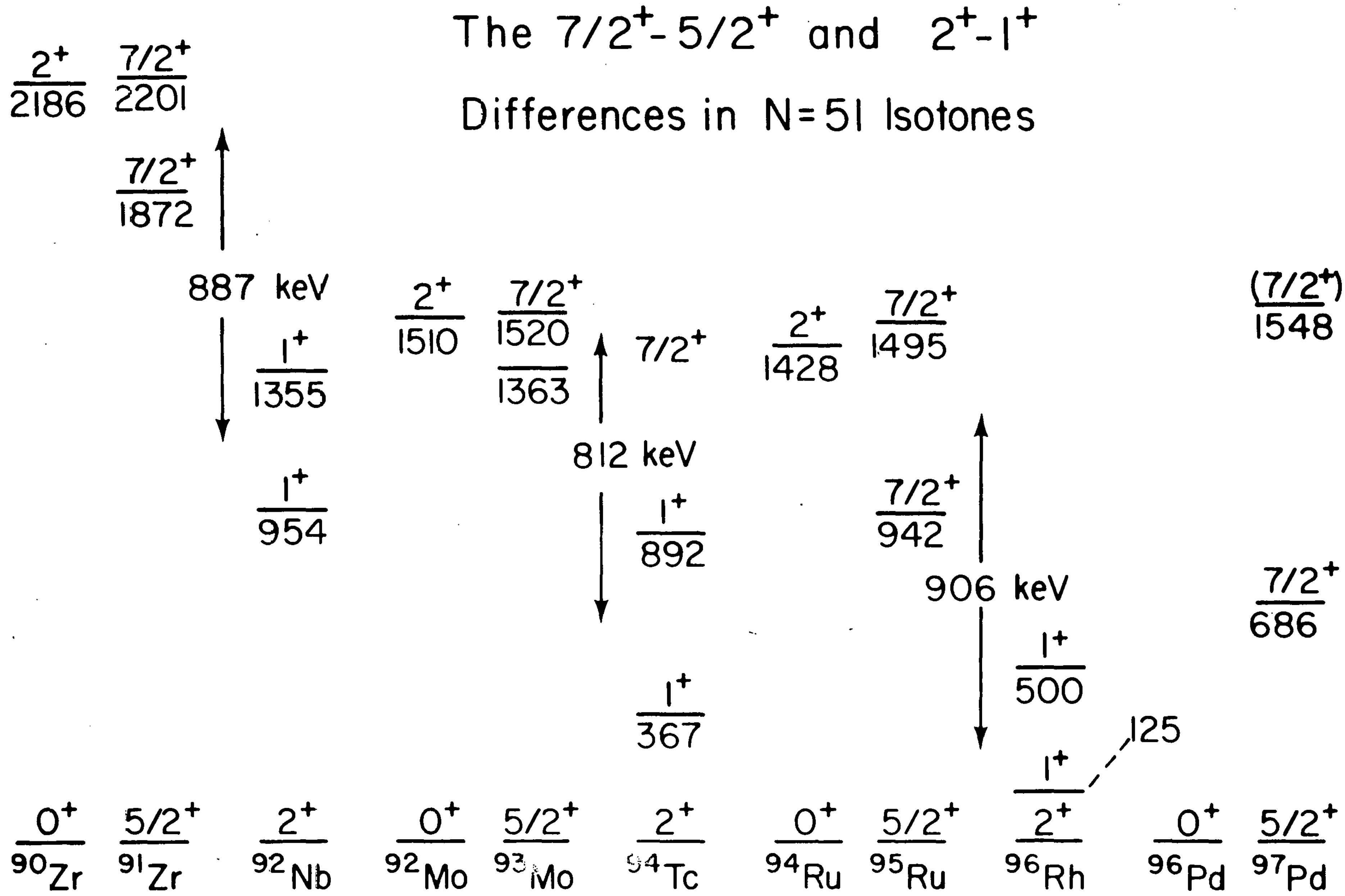


Fig. X-3. The low-lying level structure of the N=51 isotones.

XI. Other Studies of Nuclear Reaction Mechanisms

During 1980, Dr. P. W. Gallagher completed his Ph.D. thesis in which he studied the nuclidic yield distribution for the reactions of 60- to 160-MeV He^{++} ions with ^{103}Rh targets. The results were compared with the calculated yields from two widely used pre-equilibrium codes, ALICE, developed by M. Blann and co-workers (Ann. Rev. Nucl. Sci. 25, 123, 1975) and PRECQ2 developed by J. W. Wu, C. C. Chang and H. D. Holmgren (Phys. Rev. C19, 659, 1979). The experimental results are listed in Table XI-1. They show the presence of multiple cluster emission and the strong effect of proton and α-particle binding energies on the observed yields. As the parameters for the PRECQ2 code were developed around 140-MeV He^{++}-ion reaction data here at Maryland, it is not surprising that the fits to the data were better than theALICE fits.

The best fits occurred at low energy and are shown in Figs. XI-1 and XI-2 while the poorest fits occurred for nuclides both near and far from the target at high energy, as shown in Figs. XI-3 and XI-4.

Both programs allowed only one pre-equilibrium particle and thus, both could not fit the yields of nuclides near stability where the only way to dissipate 140 MeV in 2 or 3 particles is to emit those particles at high energy. The effects of fragmentation on the yields near the target are also not included in the codes. Overall, the calculated fits can be certainly considered reasonable in view of the program restrictions and it is expected that the next generation of these programs will prove even more accurate.

Table XI-1. Summary of cross sections (mb) reported for both activation analysis and in-beam gamma-ray spectroscopy

			E_{α} (MeV)		
Nuclide	60	80	120	140	160
^{106m}Ag	1.15±0.08	0.46±0.05			
^{105g}Ag	27.7±1.5	10.0±0.5	1.8±0.1	0.87±0.4	0.43±0.04
^{104g}Ag	87.8±3.7	22±1.1	5.7±1.2	7.5±1.3	
^{103g}Ag	411±14	69±4.5	24.3±1.4	11.3±1.8	6.8±1.2
^{102g}Ag	96.8±5.9	95.2±3.6	23.5±2.5	3.8±1.5	
^{101g}Ag		33.6±1.7	11.3±2.3		
^{100g}Ag			3.7±0.5		
^{105}Pd	30.7±2.6	84.1±5.9	38.4±3.7	19.2±1.6	
^{104}Pd	108±20	142±27	22±5	17.8±4.2	
^{103}Pd	439±35	252±17	78.8±9.5	67.2±4.6	
^{102}Pd	185±34	527±100	248±48	104±21	
^{101}Pd	2.4±0.3	212±18	149±13	102±10	68±8
^{100}Pd		17.6±1.2	140±17	85±10	65.3±7.5
^{99}Pd			45.7±4.8	30±3	25.3±2.9
^{98}Pd			5.8±0.9	8.1±1.2	8.3±1.2
^{104m}Rh	8.9±0.6	12.7±1.0	12.5±1.0	8.9±1.1	8.5±1.0
^{102}Rh	50.9±1.9	118±9	103±9	95±9	92.0±7.3
^{101}Rh	57.5±3.8	237±39	168±28	122±17	113±11
^{100}Rh	136±4	43.7±1.5	147±9	136±10	123±13
^{99}Rh	19.0±1.4	86.4±5.4	117±19	126±21	75.6±8.7

Table XI-1. (Continued)

			E_α (MeV)		
Nuclide	60	80	120	140	160
^{98}Rh		52.9±5.3	68±7	123±15	70±8
^{97}Rh			24±2	28.8±1.9	40.3±2.6
^{96}Rh			5.8±0.6		10.1±2.1
^{103}Ru	0.07±.005	0.35±.03	0.9±0.1	0.9±0.1	1.0±0.1
^{102}Ru	25.6±3.0	34.4±4.4	51.1±6.0	6.8±0.8	
^{101}Ru	36.0±3.0	81.9±7.2	25.4±3.3	36.0±3.4	
^{100}Ru	45.1±5.2	80.3±9.5	28.3±3.4	15.3±1.8	
^{99}Ru	8.7±1.2	23.7±2.9	2.2±0.9	6.9±1.0	
^{98}Ru		23.0±3.4	13.2±1.1	40.0±4.6	
^{97}Ru		2.9±0.2	135±7	86.1±7.2	15.1±1.6
^{96}Ru			64.1±7.5	41.0±4.1	
^{95}Ru			12.8±1.5	35.9±2.6	36.2±2.9
^{94}Ru				4.9±0.3	8.7±0.6
^{96}Tc	0.18±0.01	13.6±0.4	43±3	49±4	43.0±3.5
^{95}Tc		4.9±0.5	35±4	55.4±11.0	38.2±6.0
^{94}Tc			18.2±1.9	33.5±2.3	51.3±3.8
^{93}Tc			9.6±0.8	11.3±1.6	31±3
^{93m}Mo			11.2±0.6	12.6±1.4	16.4±0.9
^{90m}Mo					1.4±0.2
^{95g}Nb			0.31±0.15	0.47±0.17	
^{92m}Nb			0.16±0.02	0.46±0.03	
^{90g}Nb			1.8±0.1	3.2±0.2	11.5±0.6

Table XI-1. (Continued)

			E_{α} (MeV)		
Nuclide	60	80	120	140	160
^{88}Zr			0.15±0.01	0.87±0.04	3.7±0.2
^{88}Y			0.26±0.02	0.63±0.04	0.69±0.07
^{87}Y				0.85±0.04	1.4±0.1

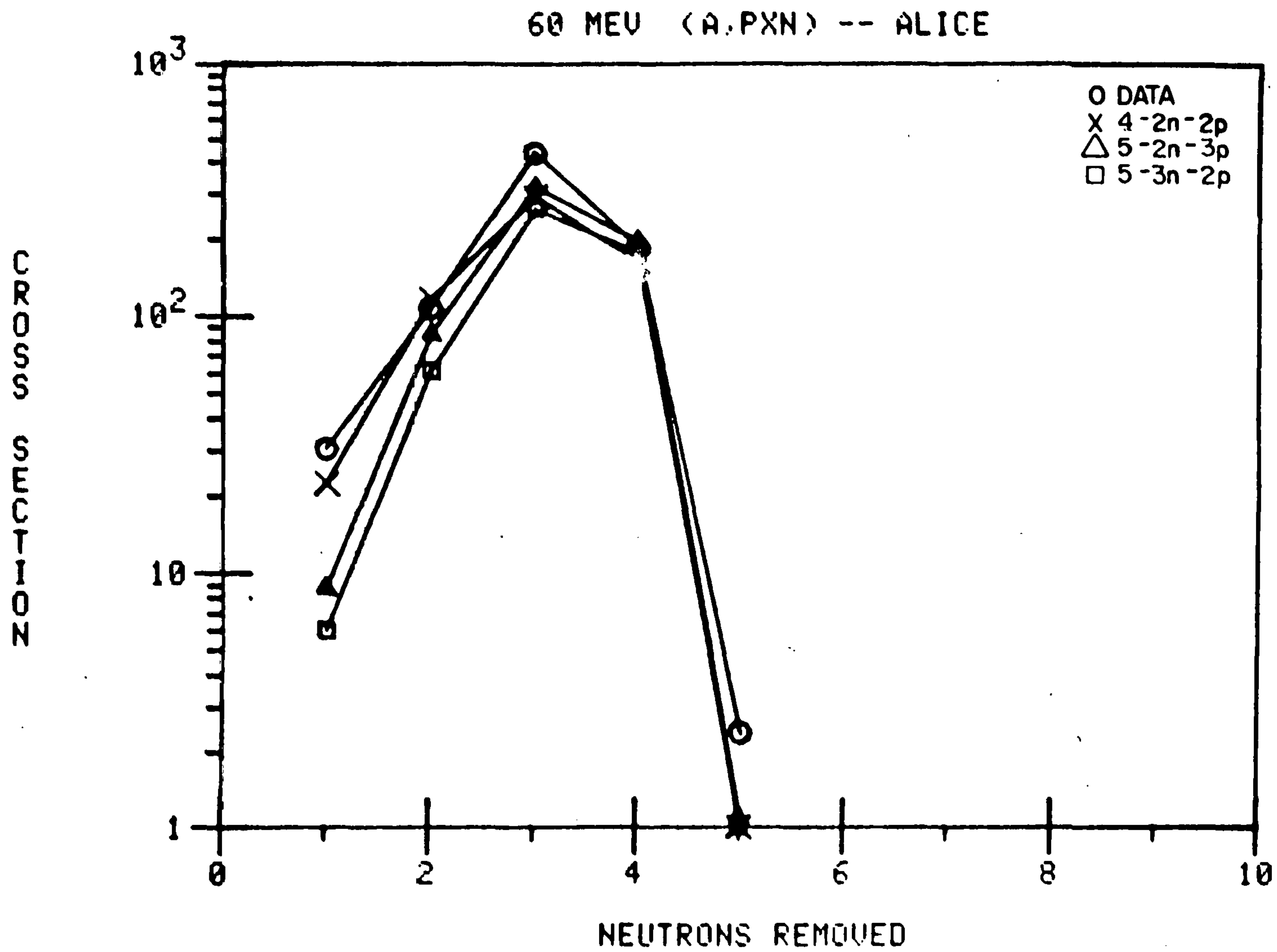


Fig. XI-1. Comparison of the yields of the Pd isotopes produced in the $^{103}Rh(\alpha,pxn)$ reaction at 60 MeV with the yields calculated by the ALICE code.

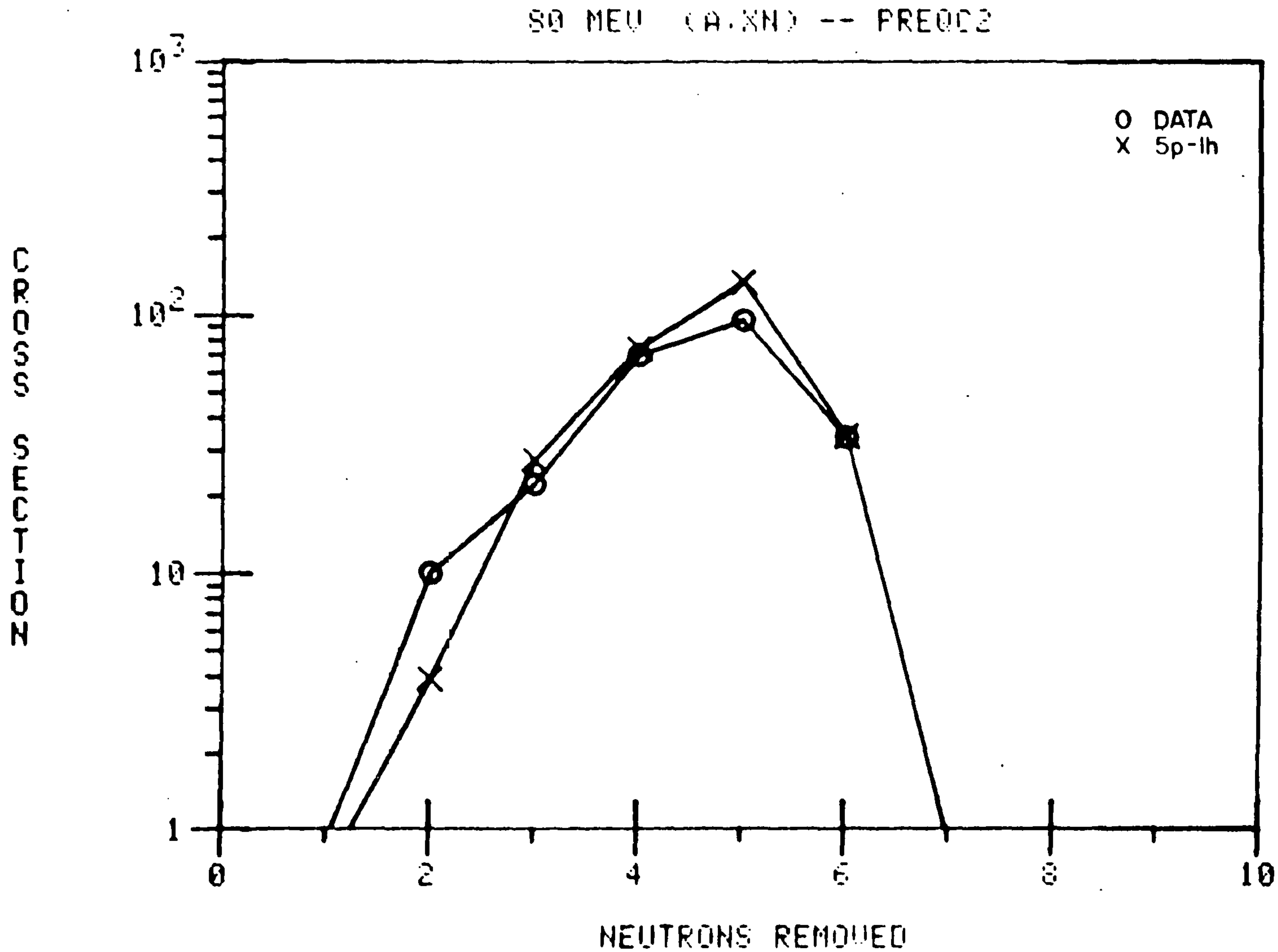


Fig. XI-2. Comparison of the yields of the Ag isotopes produced in the $^{103}Rh(\alpha,xn)$ reaction at 80 MeV with the yields calculated by the PREQC2 code.

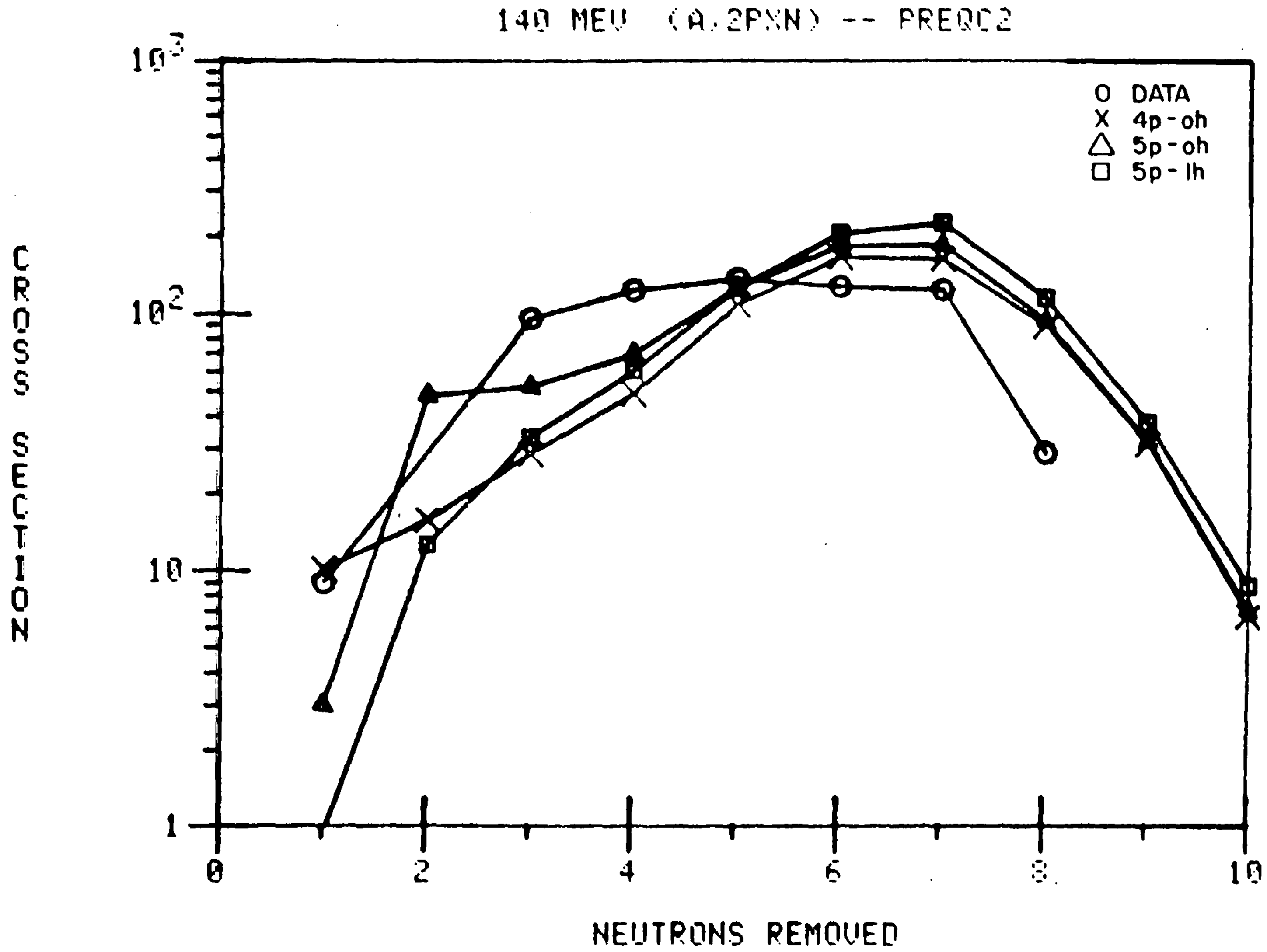


Fig. XI-3. Comparison of the yields of the Rh isotopes produced in the $^{103}Rh(\alpha,2pxn)$ reaction at 140 MeV with the yields calculated by the PREQC2 code.

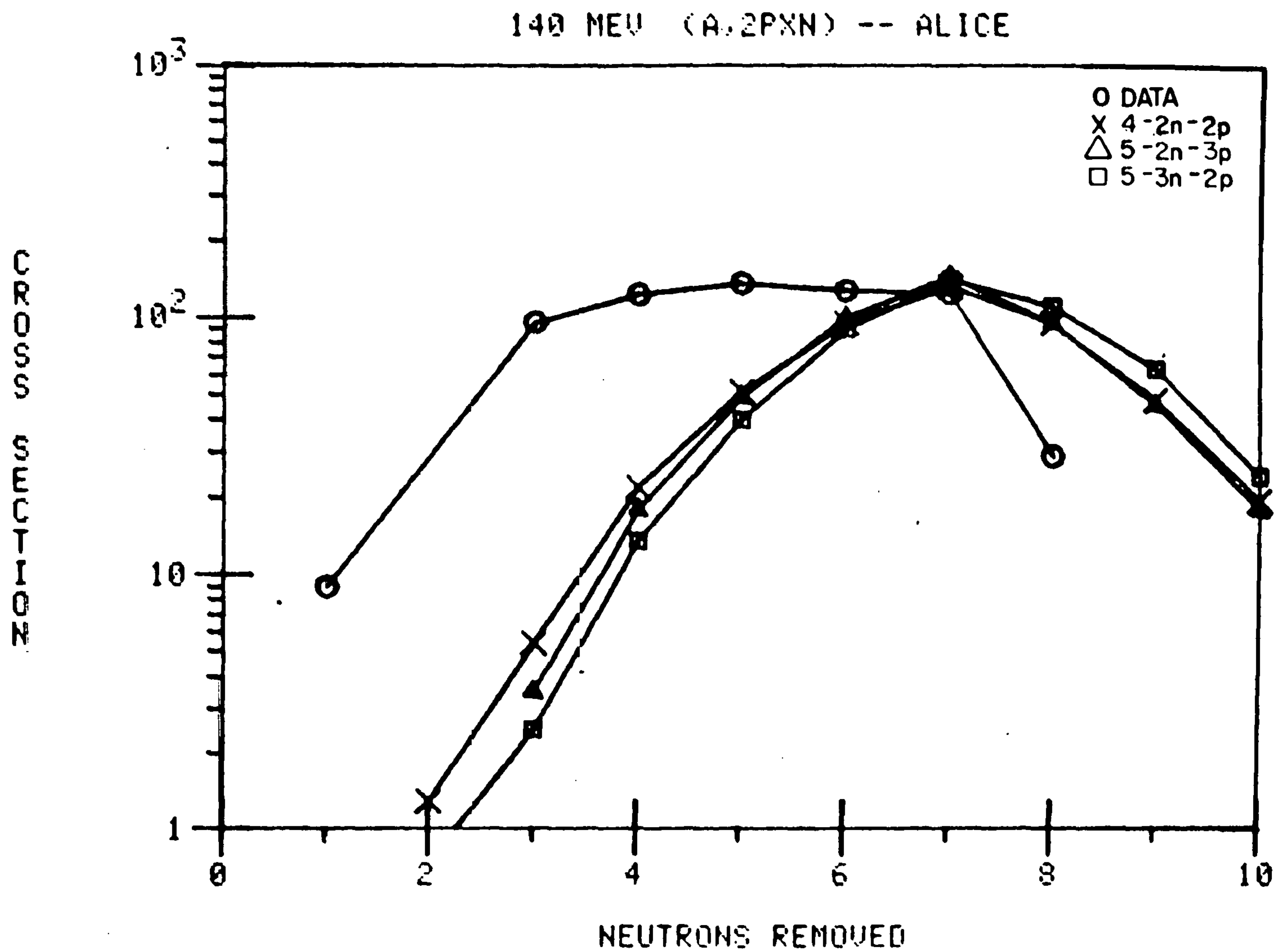


Fig. XI-4. Comparison of the yields of the Rh isotopes produced in the $^{103}Rh(\alpha,2pxn)$ reaction at 140 MeV with the yields calculated by the ALICE code.