AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

COMPETING STRUCTURES IN NUCLEI NEAR CLOSED SHELLS

Progress Report

September 1, 1993 - July 31, 1994

Stephen J. Robinson

Tennessee Technological University

Cookeville, TN 38505

July, 1994

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY

UNDER GRANT NUMBER DE-FG05-93ER40809

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER *rp*

TABLE OF CONTENTS

Preface	1
1. GRID Lifetime Measurements in ^{144}Nd	2
2. Fast Electronic Timing System.....	4
3. Massive Neutrino Searches.....	6
References	7
Appendix I : Personnel.....	8
Appendix II: Publications and Preprints	9

Preface

This report summarizes the progress made during the period September 1, 1993 through July 31, 1994 on Grant No. DOE-FG05-93ER40809.

The analysis of previously obtained GRID data on level lifetimes in ^{144}Nd has led to the identification of enhanced E2 and E3 transitions from the 5^- and 1^- states to the lowest 2^+ (quadrupole) and 3^- (octupole) states. These states have been identified as members of the quadrupole-octupole coupled (QOC) quintuplet. The errors on the absolute transition rates are compatible with a significant quasiparticle component in the wave function of the 5^- level. Lifetime measurements of positive parity states in the same nucleus have led to the identification of significant M1 components in several $2^+ \rightarrow 2^+$ transitions.

The initial steps have been taken to set up a fast electronic timing system for the measurement of level lifetimes in the picosecond range. The coupling of fast plastic scintillators and small BaF_2 crystals to fast Hamamatsu photomultipliers have been used in the first tests and in all cases pulse rise times are less than 1 ns. Initial tests of the timing resolution between plastic and BaF_2 detectors, using a ^{60}Co source, have produced a resolution of less than 200 ps.

The secretarial and accounting duties for this grant have been performed by Ms. Gloria Julian of the TTU Physics Department, and her efforts are greatly appreciated.

1. GRID Lifetime Measurements in ^{144}Nd

(collaboration with Institut Laue Langevin, Grenoble and Univ. of Göttingen, Germany)

Enhanced (several 10's of W.u.) E2 and E3 transitions from the lowest lying 2^+ and 3^- states to the 0^+ ground state in such even-even nuclei near closed shells attest to the existence of single phonon (quadrupole and octupole) vibrational excitations. It has long been realized that the coupling of these quadrupole and octupole excitations will give rise to a quintuplet of negative parity states (1^- - 5^-) with characteristic E2 and E3 decay patterns [1,2] but, to date, identification of such states has been based on enhanced E1 transitions ($\approx 10^{-3}$ W.u.) [3]. Such evidence is less direct since it relies on two body terms in the E1 transition operator [4] but, none-the-less, has indicated that the N=82, 83 and 84 nuclei is a good region to study such excitations.

An extensive experimental study of the N=84 nucleus ^{144}Nd was carried out, using the (n, γ) reaction, at the Institut Laue Langevin in Grenoble, France. Included in this study was the measurement of excited level lifetimes using the GRID technique [5]. The most significant results concern the lifetimes of negative parity states in this nucleus and the identification of enhanced E2 and E3 transitions to confirm the quadrupole-octupole coupled (QOC) nature of the 1^- and 5^- states. These results have recently been published [6] but further measurements are planned to reduce the errors on the results and also study the newly identified 4^- state [6].

The extraction of lifetime results from the GRID data is non trivial since many other factors must be taken into account, such as:

- i) Unresolved cascade feeding of the states in question.
- ii) Slowing down process in complex target (Nd_2O_3).

These factors have been studied in detail in the analysis of the ^{144}Nd GRID data.

The first problem can be overcome by calculating the cascade feeding using a statistical model of the nuclear level density and transition strengths. To check the possible influence of random variations (Porter Thomas fluctuations) in the cascade feeding calculations, ten different calculations were made for each level. Table 1 shows the average lifetime extracted using these calculations, together with the systematic variation produced by the different feeding calculations (σ_{feeding}) and the pure statistical error from the fitting procedure (σ_{stat}). As can be seen from Table 1 the systematic variation from the different feeding calculations is, in all cases, less than the statistical error in the measurement. However, it is apparent that any improvement in the statistical error in future measurements will demand a more thorough investigation of the effects of Porter Thomas fluctuations in the statistical feeding calculations.

Table 1. Variation in lifetime extracted from GRID measurements in ^{144}Nd using different feeding calculations.

Level (keV)	τ (ps)	σ_{feeding}	σ_{stat}
1510	0.81	0.03	0.10
1560	0.48	0.01	0.04
2072	0.102	0.015	0.020
2093	1.2	0.1	+1.0, -0.4
2109	1.1	0.1	+0.4, -0.3
2185	0.033	0.005	+0.040, -0.020
2295	0.28	0.01	+0.3, -0.1
2368	0.043	0.003	0.006
2453	0.0006	0.0003	+0.020, -0.0005

In the Mean Free Path Approximation (MFPA) for the analysis of GRID data [5] the slowing down process is approximated by a succession of binary collisions of the recoiling atom (Nd) with other atoms in the target material (Nd or O). It is evident that the energy lost by the recoiling atom will depend on the partner in each collision and hence the overall velocity profile will depend of the collision sequence. Since this will then affect the lifetime extracted from the measured data, a study has also been made of the effect of different collision sequences on two of the extracted lifetimes (see Table 2). In each case the collision sequence consists of a list of partner atoms for each successive collision of the recoiling Nd atom. Each sequence starts with an oxygen atom 'O', since the structure of Nd_2O_3 indicates that the three nearest neighbors of each Nd atom are all O atoms and so it is reasonable to assume that the first collision will always be with an 'O'. In the calculations each sequence is repeated until the recoiling atom is thermalized.

Table 2. Effect of different collision sequences on GRID lifetimes extracted for three levels in ^{144}Nd .

Sequence	$\tau(1560 \text{ keV})$ (ps)	$\tau(2072 \text{ keV})$ (ps)	$\tau(2185 \text{ keV})$ (ps)
O-Nd-O-Nd-O	0.48	0.10	0.033
O-Nd-O-O-Nd	0.48	0.11	0.035
O-O-Nd-O-Nd	0.49	0.11	0.040
O-Nd	0.43	0.09	0.032

The first three sequences in Table 2 preserve the stoichiometric composition of the target material (Nd_2O_3) in that the recoiling Nd atom has three 'O' collisions for every two 'Nd' collisions. These sequences produce essentially the same results for the longer living 1560 keV and 2072

keV levels since, over the (relatively) long slowing down process the variations average out. Such is not the case for the short lived 2185 keV level where all decays take place within the first few collisions and thus the extracted lifetime is sensitive to the structure of the sequence. The fourth sequence listed assumes a succession of alternating 'O' and 'Nd' collisions and as such does not reflect the target compound structure. The effect of this is most evident in the longer lifetime when the rate of energy loss is quicker, due to the increased weighting of 'Nd' collisions. Again, these results do not significantly affect the current work on Nd (due to the larger statistical errors involved), but show that such aspects must be included in any analysis of more precise data.

2. Fast Electronic Timing System

(with E. Moore and S. Mitchell, TTU undergraduate students)

Two complete photomultiplier assemblies have been purchased from Hamamatsu Corp. to start the set up of a fast timing system. These assemblies are both based on the R4998 1" diameter phototube, which has superior timing characteristics. One assembly (H5023) has been coupled to a small (1 cm diameter, 2mm thickness) plastic scintillator with a fast decay time (BC422Q). The other assembly (H5321) has a quartz window and has been coupled to a small truncated BaF₂ cone. Both assemblies are connected directly to ORTEC 9307 pico-TIMING Discriminators.

The rise time of the output pulses from the BaF₂ detector assembly has been measured using two leading edge timing modules set at 10% and 90% of the observed pulse height for various gamma-ray energies. Fig. 1 shows the results of these measurements and indicates that, within errors, the *average* risetime is independent of gamma energy between 80 keV and 1.3 MeV.

Fig. 1.
Average rise time of fast output pulses from BaF₂ detector assembly as a function of incoming gamma energy.

The average rise time over this energy range is 0.82 ns, which is a factor of three faster than that observed using a Phillips XP2020Q photomultiplier coupled to a similar BaF₂ crystal [7] in a timing system set up at ORNL. An output pulse risetime of less than 1 ns has also been observed (using a fast oscilloscope) for the plastic scintillator/H5023 photomultiplier assembly, but since the BC422Q has no energy resolution, no energy dependence of the risetime can be measured. The ratio of fast to slow light components in the prompt signal from the BaF₂ detector has been measured as approximately 25:1.

The walk characteristics and timing resolution of this system have been studied using a ⁶⁰Co source, in a close 'face-to-face' geometry. To measure the energy dependence of these factors, gates were set on small regions of the BaF₂ spectrum while a threshold was set just above the noise level on the plastic detector. The results of these measurements are shown in Figs. 2 and 3. Sarah Mitchell (TTU Undergraduate) has calculated the contribution of the detector geometry to these characteristics and found it to be negligible in this case.

Fig. 2.
Energy dependence
of the walk in the
Plastic/BaF₂ timing
system, measured
relative to an energy
of 1332 keV. Time
signals were derived
from ORTEC 9307
discriminators.

Fig. 3.
Energy dependence
of the time resolution
of the Plastic/BaF₂
timing system, using
ORTEC 9307
discriminators.

Both the walk and resolution are about the same as that observed in the ORNL timing system, but considerably worse than that obtained at TRISTAN [7]. Efforts are underway to understand and improve these factors.

One aspect which this timing system was set up to study directly is the use of low energy gammas and X-rays for fast timing. The initial step in this study was to measure the time

resolution between conversion electrons (detected in the plastic scintillator) and X-rays (31 keV) from the highly converted 662 keV transition in the decay of ^{137}Cs . So far, a resolution of 480 ps has been obtained for this system, which compares very favorably with the 630 ps obtained using the ORNL system [6] when operated in a β -X(81 keV) mode.

When using low energies it is crucial to optimize the collection of the fast (UV) light component from the BaF_2 crystal. This can be done by ensuring that the coupling between the crystal and the photomultiplier is as transparent as possible to UV light, which the crystal should be coated with a UV reflecting material. Erin Moore (TTU undergraduate) has designed and is constructing a rig to test both of these properties. Initial, qualitative, tests have indicated that calcium or magnesium carbonate would provide the best reflective properties, but a suitable medium for applying these has not yet been identified.

In addition, since the crystal does not cover the complete front window of the photomultiplier, it is desirable (to reduce noise levels) to cover the rest of the window with a material which will not reflect back light which escapes from the photomultiplier in these regions. To investigate this the residual counting rate from a photomultiplier with no crystal attached was measured, with various materials covering the front face (and sealed to be light tight). It was found that black neoprene rubber (mousepad material) gave by far the best performance in this aspect.

3. Massive Neutrino Searches

(with M. M. Hindi and R. L. Kozub)

Work on massive neutrino searches, begun before this grant was awarded (in collaboration with M. M. Hindi and R. L. Kozub of TTU) has continued. A search for a 17 keV neutrino branch in the IB spectrum of ^{125}I was concluded and a publication on this experiment is included in Appendix II of this report. In addition, initial testing of a system to measure the energy and velocity of recoiling ^{37}Cl ions, following the EC decay of ^{37}Ar , was performed at Montana State University. A paper describing this work will be published shortly in Vacuum Science and Technology. Further details of both these experiments can be found in the annual report of M. M. Hindi and R. L. Kozub (Grant No. DE-FG05-87ER40314).

References

- [1] P. Lipas, Nucl. Phys. **82** (1966) 91.
- [2] P. Vogel and L. Kochach, Nucl. Phys. **A176** (1971) 33.
- [3] R. A. Gatenby et al., Nucl. Phys. **A560** (1993) 633.
- [4] A. F. Barfield et al., Z. Phys. A **332** (1989) 29.
- [5] H. G. Börner and J. Jolie, J. Phys. G **19** (1993) 217.
- [6] S. J. Robinson et al., Phys. Rev. Lett. **73** (1994) 412.
- [7] P. K. Joshi et al., Nucl. Instrum. Methods A **335** (1993) 461.
- [8] M. Moszynski and H. Mach, Nucl. Instrum. Methods A **277** (1989) 407.

Appendix I : Personnel

FACULTY

Stephen J. Robinson

TTU UNDERGRADUATES

Erin A. Moore

Part time, Summer 1994

Sarah Mitchell

Part time, Summer 1994

COLLABORATORS

H. G. Börner

Institut Laue Langevin, Grenoble, France

J. Jolie

Institut Laue Langevin, Grenoble, France

K. P. Lieb

University of Göttingen, Germany

E. F. Zganjar

Louisiana State University

P. K. Joshi

Louisiana State University

M. M. Hindi

Tennessee Technological University

R. L. Kozub

Tennessee Technological University

Appendix II: Publications and Preprints

PUBLISHED ARTICLES

"E2 and E3 Transitions from Quadrupole-Octupole Coupled States in ^{144}Nd "

S. J. Robinson, J. Jolie, H. G. Börner, P. Schillebeeckx, S. Ulbig and K. P. Lieb, Phys. Rev. Lett. **73** (1994) 412.

"Search for a 17 keV neutrino in the internal bremsstrahlung spectrum of ^{125}I "

M. M. Hindi, R. L. Kozub and S. J. Robinson, Phys. Rev. C **49** (1994) 3289.

ARTICLES IN PRESS

"Lifetimes of the 0^+_2 Configuration in ^{186}Hg and ^{188}Hg "

P. K. Joshi, E. F. Zganjar, D. Rupnik, S. J. Robinson, P. F. Mantica, H. K. Carter, J. Kormicki, R. L. Gill, W. B. Walters, C. R. Bingham, A. V. Ramayya, W. C. Ma and J. H. Hamilton, to be published in Int. J. Mod. Phys. E.

"Neutrino Recoil Induced Desorption"

L. Zhu, R. Avci, G. J. Lapeyre, M. M. Hindi, R. L. Kozub and S. J. Robinson, to be published in J. Vacuum Sci. and Tech.

Reprint removed

DATE

FILMED

9 / 27 / 94

END