Sponsor: Department of Energy, Oak Ridge Operations

Type Agreement: Contract No. DE-AS05-80ER10599 Mod A003

Award Period: From 2/1/83 To 1/31/84

Sponsor Amount: Total Estimated: $ 275,000

Cost Sharing Amount: None

Title: Nuclear Structure From Radioactive Decay

ADMINISTRATIVE DATA

1) Sponsor Technical Contact:

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Military Security Classification: None

See Attached Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with None proposed or anticipated

COMMENTS:

Mod. A003 adds $85,000 partial funding through 1/31/84.

Revised total contract value (including prior project numbers) is $275,000

ORIGINAL REVISION NO. 2/17/83
GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date May 2, 1984

Project No. G-41-636

School/XXX Physics

Includes Subproject No.(s)

Project Director(s) J.L. Wood

GTRI / XXX

Sponsor Department of Energy, Oak Ridge Operations

Title "Nuclear Structure from Radioactive Decay"

Effective Completion Date: 1/31/84 (Performance) (Reports)

Grant/Contract Closeout Actions Remaining:

[ ] None
[ ] Final Invoice or Final Fiscal Report
[ ] Closing Documents
[ ] Final Report of Inventions
[ ] Govt. Property Inventory & Related Certificate
[ ] Classified Material Certificate
[ ] Other

Continues Project No. G-41-630

Continued by Project No. G-41-663

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**Type of Document ("X" one)**

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|  | 4c. Are there any patent related objections to the release of this information product? If so, state these objections. |

**Submitted by**

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**Signature**

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**FOR DOE USE ONLY**

|  | 5a. Patent clearance has been granted by responsible DOE patent group. |
|  | 5b. Report has been sent to responsible DOE patent group for clearance. |
|  | 5c. Patent clearance not required. |

**Date 8/31/83**
NUCLEAR STRUCTURE FROM RADIOACTIVE DECAY

Annual Progress Report
U. S. Department of Energy
Contract DE-AS05-80ER10599

J. L. Wood
Senior Research Scientist and Principal Investigator

September 30, 1983

School of Physics
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Atlanta, Georgia 30332

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1.0 Introductory Overview

The most exciting development during this year was the first ever nuclear orientation study of nuclear spins and transition multipolarities on-line to an isotope separator. This was a UNISOR/LISOL (Leuven Isotope Separator On-Line) collaboration: the on-line nuclear orientation experiments being done at LISOL, which is operated on-line to the CYCLONE cyclotron at Louvain-la-Neuve, Belgium. The subject chosen for study was dynamical supersymmetries in $^{191}$Au.

In the past year a major effort has gone into the study of structural features in nuclei that lie outside of the model space of the interacting boson model (IBM). The important additional building blocks needed have been identified from systematic features in experimental data. A variety of programs of calculation have been initiated. Invited talks on the subject were given at the Workshop on Boson Models in Nuclei held at Drexel University, Philadelphia, 28-29 January, 1983 and at the Workshop in Nuclear Collective States held at Suzhou University in the People's Republic of China, 8-18 September, 1983. Papers are in preparation for the proceedings of these workshops. This is a continuation of a critical assessment of experimental tests of the IBM, which was published in Nuclear Physics A early this year.

The program of investigation of shape coexistence in nuclei in collaboration with Prof. K. Heyde (Gent, Belgium) continues. The review entitled "Coexistence in Odd-Mass Nuclei" done in collaboration with K. Heyde and coworkers (Gent) and R. A. Meyer (LLNL) has been refereed and final corrections are being made. It will appear as an issue of Physics Reports. The detailed study of coexistence in $^{114}$Cd made in collaboration
with K. Heyde (Gent) and experimental groups in Grenoble, France and Munich, West Germany has been accepted for publication in *Nuclear Physics A*. Preliminary ideas for a unified view of shape coexistence in nuclei have appeared in a Conference Proceedings. The groundwork for a review of coexistence in even-mass nuclei is being laid. This provides a vital clue to the role of non-valence shell degrees of freedom, which lie outside of the IBA model space (see above). A visit to Gent was made in July, 1983 in the continuation of this program.

Experiments at UNISOR have been extremely sparse. This is because of the very limited terminal voltage (less than 16.5 MV) available on the tandem. A further attempt to produce very neutron-deficient Au isotopes was made by bombarding Sm targets with $^{35}$Cl beams. (This was severely constrained since the 16.3 MV available on terminal barely enabled the $^{35}$Cl ions to overcome the Coulomb barriers of the $^{147,150}$Sm targets.) Some $\gamma$-ray multiscaling data were obtained for $^{181}$Au and the isotope $^{178}$Au was identified by a spectroscopy. However, very successful $\gamma\gamma$ coincidence studies of the decays of $^{191m,8}$Hg to levels in $^{191}$Au were made. This constituted the UNISOR contribution in the UNISOR/LISOL study of dynamical supersymmetries in $^{191}$Au (see above). Work has continued on data reduction and decay scheme construction. The study of the level scheme of $^{187}$Pt will be published in *Nuclear Physics A*. This study constituted part of the Ph.D. thesis work of Mr. B. E. Gnade of the Georgia Tech School of Chemistry. This thesis was awarded a Georgia Tech Sigma Xi Physics prize in April 1983.

A twelve day visit to TRISTAN was made in April 1983 to use the newly developed FEBAID ion source. Although the run was unsuccessful, due to technical difficulties, considerable progress was made in making the TRISTAN
on-line conversion electron detector operational. The importance of this to nuclear structure studies at TRISTAN is discussed in the appropriate sections below. Other visits to TRISTAN are planned for later this year.

Other activities have included seminars given at the Universities of Cologne and Mainz and at GSI, Darmstadt, West Germany in July/August 1983 and a colloquium and seminar at the University of Arizona, Tucson. The author has continued to serve on the TRISTAN Executive Committee. A paper entitled "Dynamical Groups of Liquid Drop Models," in collaboration with R. Gilmore, D. H. Feng and M. Vallieres (Drexel University, Philadelphia) has been published in Physical Review C. Finally, the author will be a half-time visiting professor at Drexel University, Oct. 1 - Dec. 15, 1983.

2.0 Experimental Program

A major area of activity is the study of neutron-deficient nuclei around the Z = 82 shell closure, with special emphasis on the levels of the odd-mass Pt, Au, Hg and Tl isotopes. A crucial ingredient of this work is the systematic investigation of low-energy structural features of sequences of isotopes (and isotones) over many adjacent mass numbers. This has a two-fold purpose. First, it enables us to build up a very complete picture of the nuclear structure that connects the regions of stable nuclei (where, e.g., transfer reactions and Coulomb excitation permit the measurement of detailed spectroscopic properties) with regions far from stability, where detailed spectroscopic information is very limited. Second, it provides a map of the excitation degrees of freedom as a function of the changing proton and neutron number over broad mass regions. The mass region under study possesses the richest variety of nuclear excitations observed anywhere on the mass surface. It is intersected by the Z = 82 shell closure, and
bounded by the strongly deformed nuclei with $Z \leq 76$ and the $N = 126$ shell closure. Between $Z = 76$ and $Z = 82$ there is a shape transition from strongly deformed prolate axial symmetry through oblate axial asymmetry to spherical symmetry. This transition has alternatively been described in terms of the interacting boson approximation (IBA) as a transition from the SU(3) through the O(6) limiting algebraic symmetries of the IBA Hamiltonian.

Finally, and most dramatically of all, an island of ground state deformation has been established adjacent to the $Z = 82$ closed shell for the very neutron-deficient isotopes of Hg and Pt. This deformation is now understood in terms of proton intruder orbitals which give rise to the large deformation ($\beta \sim 0.27$) through an increased proton valence space and the proton-neutron residual interaction.

Extremely complex decay schemes result from the coexistence of normal and intruder state configurations in neutron-deficient odd-mass nuclei in the Pt, Au, Hg region. The details of these schemes can be resolved by a technique of "running" coincidence gates which is able to separate $\gamma$-ray and conversion electron spectra into discrete components as close as one-tenth full-width-at-half-maximum of the detection system resolution. The limiting factor in this procedure is that it necessitates setting a total of about one thousand coincidence gates per coincidence data set! Higher resolution $\gamma$-ray detectors, such as the new Ganna-X™ Ortec detectors, improve this situation considerably. However, we have found in our studies of very high statistical quality ($1-2 \times 10^7$ coincidence events) that weak lines give rise to an enormous line density.

A significant shift has occurred in the thrust of the experimental program in the past year. The groundwork for a study of coexistence in even-mass nuclei has revealed that this degree of freedom is far more important in the low-energy structure of heavy nuclei ($A \gtrsim 56$) than has been previously realized.
Further, there is a severe lack of suitable experimental data in heavy nuclei. Consequently, the emphasis of the experimental program is shifting to address this situation. Besides the ongoing program of experimental studies near Z = 82 at UNISOR, studies near Z = 50, especially at TRISTAN are going to be of considerable importance. This is discussed in greater detail in the accompanying Renewal Proposal.

2.1 Odd-Mass Au Decays

The study of the $^{187}$Au $\rightarrow$ $^{187}$Pt decay scheme is completed. A paper is in press with Nuclear Physics A. This work constituted part of the Ph.D. thesis research of B. E. Gnade (School of Chemistry, Georgia Tech) to whom the author served as principal thesis advisor. This thesis was awarded a Georgia Tech Sigma Xi Physics prize in April 1983. The study of the $^{189}$Au $\rightarrow$ $^{189}$Pt decay scheme still requires conversion electron data.

A second attempt to produce very neutron-deficient Au isotopes was made by bombarding $^{147,150}$Sm targets with 163 MeV $^{35}$Cl ions (corresponding to a voltage of 16.3 MV on the tandem terminal). This was just sufficient for the $^{35}$Cl ions to clear the Coulomb barrier and resulted in ($^{35}$Cl, 4n) reactions leading to activities of $^{181}$Au and $^{178}$Au. The former was studied by $\gamma$-ray multiscaling and the latter was identified by $\alpha$ spectroscopy. Various technical problems were encountered, most notably the beam (typical currents $\sim$ 70 pnA) was insufficiently defocussed to prevent target damage due to heating. This problem is being worked on by the UNISOR technical staff.

2.2 Odd-Mass Hg Decays

The most significant activity this year has been a study of the decays of $^{191m}$Hg (50 min) and $^{191g}$Hg (37 min) to excited states in $^{191}$Au. This is
aimed at determining the validity of a dynamical supersymmetry classification for levels and electromagnetic transitions in $^{191}$Au. Excellent $\gamma\gamma$-coincidence data were obtained at UNISOR for both decays, using bombardments of Hf and Ta targets with $^{16}$O beams of 105 MeV energy from the tandem (the low beam energy placed only modest demands on the terminal voltage). The $^{191m}$Hg was produced directly by the $^{180}$Hf ($^{16}$O, 5n) reaction and the $^{191}$Hg (low spin) was produced indirectly from the decay of $^{191m}$Tl following the $^{181}$Ta ($^{16}$O, 6n) reaction. Most exciting of all was a study of the same decays (following the same production reactions) using low-temperature nuclear orientation. This was done in collaboration with the on-line low-temperature nuclear orientation group of L. Vanneste at Leuven Belgium. This facility is operated on-line to the LISOL (Leuven Isotope Separator On Line) facility at the CYCLONE cyclotron in Louvain-la-Neuve, Belgium. These latter studies are vital for providing unique spin assignments to excited states and accurate transition multipolarities in $^{191}$Au. Such information is crucial for a reliable test of dynamical supersymmetries. The UNISOR institutions involved in this work are Georgia Tech School of Physics (principal investigators), LSU, Vanderbilt and UNISOR staff. Also, Prof. K. Krane of Oregon State University, Corvallis—a leading expert in nuclear structure information from low-temperature nuclear orientation—is a collaborator. The data are in the process of being analyzed.

The immense task of elucidating the $^{187m,8}$Hg $\rightarrow$ $^{187}$Au decay scheme continues. This is being assisted by our study of the very similar $^{185}$Au level scheme. The extreme complexity arises because of coexisting bands of particle states (based on the $\pi h_9/2$ and $\pi f_{13/2}$ orbitals) and coexisting bands of hole states (based on the $\pi d_{3/2}$, $\pi d_{5/2}$ and $\pi h_{11/2}$ orbitals). The enormous task of coincidence gate pulling for $^{187}$Au is essentially completed. A critical point (that has demanded extreme care) is that a recent study of $^{185}$Au by
C. Bourgeois, et al., Nucl. Phys. A386, 308 (1982), invokes a new kind of highly converted M1 transition - we completely disagree - contending that the abnormal conversion is due to strong E0 transitions (which are incorrectly placed in the rival work). We are in the process of writing a large paper on the odd-Au isotopes. This work is being done in collaboration with E. F. Zganjar (LSU) and M. A. Grimm (Univ. of Louisville).

2.3 Odd-Mass Tl Decays

The elucidation of the $^{187m,s}Tl \rightarrow ^{187}Hg$ and $^{189m}Tl \rightarrow ^{189}Hg$ decay schemes continues. A vital step following on from the systematic features that we have asserted for these isotopes, and the probable discovery of the Nilsson state $9/2^+ 624$ as a 33 ns isomer in $^{187}Hg$, is to identify the other Nilsson states expected close to the Fermi energy in $^{187}Hg$. This is being pursued through the construction of a detailed level scheme for $^{187}Hg$. The systematics of the $i_{13/2}$ band in $^{187-197}Hg$ is being prepared for publication. This work is being done in collaboration with E. F. Zganjar (LSU).

As a "windfall" in the $^{191m,s}Hg \rightarrow ^{191}Au$ studies (see Sect. 2.2 above), we obtained excellent $\gamma\gamma$-coincidence data on the $^{191m}Tl \rightarrow ^{191}Hg$ decay scheme. These data are being analyzed.

2.4 Odd-Mass Pb Decays

The elucidation of the $^{198m}Pb \rightarrow ^{198}Tl$, $^{191m}Pb \rightarrow ^{191}Tl$, and $^{193m}Pb \rightarrow ^{193}Tl$ decay schemes has been temporarily halted due to the heavy data analysis load in other areas. (These studies are being done in collaboration with E. F. Zganjar (LSU) and L. L. Riedinger (Univ. of Tennessee). The $^{189m}Pb$ decay study also involves a collaboration with the DSI, Darmstadt separator group.)
2.5 The Decay of $^{120m_1,m_2,8}$In $\rightarrow ^{120}$Sn

Our first experiment at the TRISTAN facility took place in April 1983. This was to study the decays of the three $\beta$-decaying states in $^{120}$In to excited states in $^{120}$Sn, using a FEBIAD ion source developed at TRISTAN late last year. The experiment failed because of technical problems with this ion source. However, since April, successful operation of a FEBIAD ion source has resumed and we will plan to repeat the experiment later this year.

2.6 Other Decay Scheme Studies

The study of the $^{201m,8}$Po $\rightarrow ^{201}$Bi decay schemes is being prepared for publication. This work is being done in collaboration with R. A. Braga (School of Chemistry, Georgia Tech). Other experiments proposed for UNISOR (see Renewal Proposal, 1981 or the accompanying Renewal Proposal) await beam time at HHIRF.

3.0 Nuclear Systematics and Models

The major activity on this contract in the past year has been the continuing program of development of nuclear systematics and models for a better understanding of nuclear structure. At a time when the ability to generate experimental data has become enormous and the manpower available to reduce these data and extract information on nuclear structure has become extremely limited - severe constraints are needed on which topics are chosen for experimental study. The author regards the development of nuclear systematics and the development and testing of nuclear models as the most vital feature of the present program. Without the discipline of such a program, the explosion of information on nuclear structure will soon completely overwhelm the
community of physicists who study the nuclear many-body problem. It is essential to recognize that the exploration of nuclear structure needs to be pursued on paths that have some promise of convergence.

In this respect, the interacting boson model (IBM) has been a development of major significance for nuclear structure. It continues to accommodate the vast array of phenomena being observed, nine years after its inception. A thorough-going assessment of experimental tests of the IBM in its simplest forms has been completed and published in *Nuclear Physics A*. The program has continued in two (related) directions. The first line of development has been to thoroughly look at the experimental evidence for factors that influence low-energy nuclear structure which lie outside of the model space of the IBM. The second line of development has been to evaluate the evidence for shape coexistence in even-mass nuclei.

The role of coexisting collective bands (and coexisting shapes) in low-energy nuclear structure has become a major theme under this contract. This has stemmed from the crucial influence that shape coexistence has on the low-energy structure of the neutron-deficient Pt, Au, Hg and Tl isotopes that have been and are being studied at UNISOR. It has been furthered by the exploration of shape coexistence, not only in odd-mass nuclei of the above isotopes, but in all heavy odd-mass nuclei. This has resulted in a review of the subject of coexistence in odd-mass nuclei done in collaboration with K. Heyde and coworkers (Gent, Belgium) and R. A. Meyer (Lawrence Livermore National Laboratory), which is to be published as an issue of *Physics Reports* (final responses to the referees comments are being made). A formulation in terms of the IBM (developed by P. Duval and B. R. Barrett, Univ. of Arizona, Tucson) has been investigated, in collaboration with K. Heyde, for the nucleus $^{114}$Cd. This nucleus has been extremely well studied by experimental
groups at ILL, Grenoble, France, using (n,γ) and (n,e⁻) spectroscopy and at TU, Munich, West Germany, using (d,p) transfer reaction spectroscopy. A joint paper has been accepted for publication in Nuclear Physics A. A unified view of shape coexistence in nuclei has been developed and a preliminary discussion of the idea has been published in Proceedings of the Conference on Lasers in Nuclear Physics, Oak Ridge, April, 1982.

Currently, the groundwork is being laid for exploring degrees of freedom outside of the IBM model space, and especially coexistence in even-mass nuclei (which is being done in collaboration with K. Heyde). Invited talks have been given at the Workshop on Boson Models in Nuclei held at Drexel University, Philadelphia, 28-29 January, 1983 and at the Workshop in Nuclear Collective States held at Suzhou University in the People's Republic of China, 8-18 September, 1983. Papers are in preparation for the proceedings of these workshops. A study of the description of collective negative parity states in deformed nuclei in terms of an f boson has been started in collaboration with B. R. Barrett (Univ. of Arizona) and one of his graduate students. A visit to Tucson was made in March 1983 to pursue this program. A connection to more formal aspects of nuclear collectivity has been made in a study of dynamical groups of liquid drop models, done in a collaboration with R. Gilmore, D. H. Feng and M. Vallieres (Drexel University). A paper has been published in Physical Review C.

Finally, a study of particle-core coupling models and the description of collective states in the odd-mass Pt, Au, Hg and Tl isotopes is being made in collaboration with P. Semmes (School of Chemistry, Georgia Tech) and G. Leander (UNISOR). This will constitute part of the doctoral thesis of Mr. P. Semmes.

The pursuit of nuclear systematics and models, as it relates to degrees
of freedom outside of the IBM model space and shape coexistence, brings three areas of the above experimental program into focus: (i) The near degenerate coexisting shapes in the neutron-deficient Pt, Au, Hg and Tl region. (ii) The existence of well-defined coexisting collective bands in the even-mass Sn and Cd isotopes. (iii) The observation of all degrees of freedom below 3 MeV in the even-Sn isotopes. The first topic continues to be a major area of study because of its uniqueness. The second and third topics are accessible at TRISTAN. In particular, the study of levels in $^{120}$Sn will provide vital information relating to topics (ii) and (iii). Of especial note for the TRISTAN studies is the importance of EO transitions which appear to be the most universal signature of coexisting bands. Future experimental plans which emphasize these three items appear in the accompanying Renewal Proposal.

4.0 Personnel

Senior Staff:

Dr. J. L. Wood, Senior Research Scientist, Principal Investigator (Full time, Feb. 1 - Sept. 30, Dec. 16 - Jan. 31 (9 1/2 months); Half time, Oct. 1 - Dec. 15 (2 1/2 months)).

Graduate Students:

Mr. Chris Papanicolooulos, Ph.D. thesis work (Half time research assistant, 12 months).

5.0 Summary of Publications and Preprints, Abstracts, Presentations at Conferences, and Outside Seminars, 1983.


