

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

CAG

Date: April 6, 1977

Project Title: *Nuclear and X-Ray Spectroscopy with Radioactive Sources*

Project No: *G-33-622 (continuation of G-33-611)*

Project Director: *Dr. R. W. Fink*

Sponsor: *Energy Research and Development Administration; Oak Ridge, TN 37830*

Agreement Period: From 2/1/77 Until 1/31/78

Type Agreement:

Contract No. EY-76-S-05-3346; Modification No. 13

Amount:

*\$70,500 ERDA Funds
76,229 GIT (G-33-391)
\$146,729 Total Estimated Cost*

Reports Required:

*Publication Preprints; Publication Reprints; Annual Progress Report;
Final Report*

Sponsor Contact Person (s):

Technical Matters

Contractual Matters

(thru OCA)

*Mr. Earl Mason
Research Contracts, Procedures & Reports Branch
Contract Division, U.S. Energy Research and Development Administration
Oak Ridge Operations
P.O. Box E
Oak Ridge, TN 37830
Phone: (715) 483-8611 ext. 34105*

Defense Priority Rating: *none*

Assigned to: Chemistry (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director-EES
Accounting Office
Procurement Office
Security Coordinator (OCA)
Reports Coordinator (OCA) ✓

Library, Technical Reports Section
Office of Computing Services
Director, Physical Plant
EES Information Office
Project File (OCA)
Project Code (GTRI)
Other _____

E-33-622

ORO-3346-214

NUCLEAR AND X-RAY SPECTROSCOPY WITH RADIOACTIVE SOURCES

Thirteenth Annual Progress Report
U. S. Energy Research and Development Administration
Department of Energy
E-(40-1)-3346

R. W. Fink
Professor of Chemistry & Senior Investigator

October 31, 1977

1977



School of Chemistry

GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

(404) 894-4030

NUCLEAR AND X-RAY SPECTROSCOPY WITH RADIOACTIVE SOURCES

Thirteenth Annual Progress Report

U. S. Energy Research and Development Administration

Department of Energy

Contract E-(40-1)-3346

R. W. Fink

Professor of Chemistry

Senior Investigator

October 31, 1977

School of Chemistry

Georgia Institute of Technology

Atlanta, Georgia 30332

Telephone (404) 894-4030

	Page
1.0 Highlights	1
2.0 Nuclear Spectroscopy	3
2.1 Nuclear Systematics and Models	3
2.1.1 Particle-Core Coupling and Effective Cores	4
2.1.2 Triaxial Rotor Model	5
2.1.3 The Shell Model and Intruder States	7
2.1.4 Pairing and Residual Interactions in the Shell Model of Heavy Nuclei	8
2.2 Completed Experimental Studies	9
2.2.1 Decay of Odd-Mass $^{189-193}\text{Hg}$ Isotopes	9
2.2.2 Decay of Odd-Mass $^{189-197}\text{Tl}$ Isotopes	10
2.2.3 Decay of $^{197\text{m},\text{g}}\text{Pb}$	10
2.3 Current Experimental Investigations	11
2.3.1 Decay of $^{185,187}\text{Hg}$ Isotopes	11
2.3.2 Decay of $^{201\text{m},\text{g}}\text{Po}$ and $^{201\text{m},\text{g}}\text{Bi}$ Isobars	12
2.3.3 Decay of Odd-Mass $^{185-189}\text{Au}$ Isotopes	12
2.3.4 Decay of $^{185,187}\text{Tl}$ Isotopes	13
2.3.5 Nuclear Lifetime Measurements	13
2.3.6 Other Work	14
2.4 International Comparison of ^{152}Eu Calibration Standards	15
3.0 Fast Neutron Research	19
3.1 A ^6LiD Irradiation Capsule for Producing 14 ± 2 MeV Neutrons in the Reactor	19
3.2 Use of the ^6LiD Capsule for Decay Study of ^{173}Tm	20
4.0 X-rays from Radioactive Sources	24
4.1 Tables for Handbook of Spectroscopy, 2nd Ed.	24
4.2 Experimental Measurement of the L-Subshell X-ray Fluorescence and Coster-Kronig Transition Yields at $Z = 67$	24
5.0 Miscellaneous Topics	25
5.1 Advisory Board Activities for Handbook of Spectroscopy, 2nd Ed.	25
5.2 Tables of Thermal Neutron Cross Sections	25
5.3 Development of Computer Programs	25
5.3.1 Codes for the Analysis of Singles Data: SKEWGAUS and PEAKFIND	26
5.3.2 New Codes for Coincidence Data: PRESCN and GATESCN	26
5.3.3. Codes for the Nuclear Data ND-4420 and the PDP-15 Computers	27

	Page
6.0 Equipment Added During 1977	28
7.0 Personnel	29
8.0 List of Publications, Presentations at Meetings, Lecture Tours and Outside Seminars 1977	30

1.0 HIGHLIGHTS

With the completion in December 1976 of the Ph.D. thesis of Gregory M. Gowdy on the decay of odd mass thallium isotopes and the nuclear structure of odd mass mercury daughter isotopes, a major area of initial UNISOR research was concluded. This thesis won the Georgia Tech Sigma Xi Research Prize (\$200) for the best thesis of the year, and Dr. Gowdy will take up a guest scientist position in October, 1977, at the Gesellschaft für Schwerionenphysik (GSI), Darmstadt, West Germany, where he will mainly be associated with the on-line isotope separator program.

During the nine-month period (December, 1976-August, 1977) that the ORIC machine has been shutdown for adaptation to the new 25 MV folded tandem injector accelerator, a large effort has been devoted by us to the finalization of the decay scheme studies of odd mass $^{189-197}\text{Tl}$ and $^{189-193}\text{Hg}$ isotopes. This work involved an immense amount of data processing, cataloging, and cross-correlating of systematic features. Dr. Gowdy was appointed as a research associate in our group during the summer 1977 to assist in the final stages of this task. At this writing, eight full journal manuscripts based on this work are nearing completion and will be submitted for publication during 1977. The specifics are described in sections below. Embodied in these eight manuscripts is a large amount of new information on the systematic features of the low-energy nuclear structures of odd mass Hg and Au nuclei. Establishment of this nuclear structure information serves as a basis for the comparison between rotational and vibrational models of nuclei in this transitional region.

Another primary research area where considerable progress has been made this year is the study carried out by Dr. J. L. Wood of intruder states and the role of quadrupole pairing in low-energy nuclear structure. Our current thinking is that in addition to quadrupole pairing, the residual n-p force plays a major

role in the interpretation of intruder states. We believe that the mechanism through which the n-p force operates involves a proton pair-neutron pair interaction. This is amplified further below.

Other highlights of this year include the extensive experimental data on mass separated ^{187}Hg and ^{187}Au isobars (which are crucial to our investigation of strongly deformed nuclei in this transition region) obtained by our graduate student, Mr. Marvin A. Grimm, who received an ORAU fellowship for UNISOR thesis research. Very fast timing equipment, including ARC timers, lead-loaded plastic scintillators and associated photomultiplier, and software programming of our ND-4420 multiparameter analyzer for lifetime measurements of nuclear levels has been tested and made operational by Dr. R. A. Braga. New programs for the Georgia Tech CDC-Cyber-70 computer have been developed by Dr. W. R. Western and are in use for analysis of both UNISOR and on-campus data. At UNISOR the study of nuclei above the $Z = 82$ shell closure, namely isotopes of Bi and Po, has been started this year.

In order to test the accuracy of our gamma-ray intensity measurements, our entire group, coordinated by Dr. R. A. Braga, participated in an international comparison of ^{152}Eu calibration standards organized by the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, West Germany, and the National Bureau of Standards. A full description appears below, and unofficially we have been informed that our set of measurements was among the six best out of approximately 30 reporting laboratories around the world.

As part of the Ph.D. thesis research of one of our graduate students, Mr. Chris Papanicolopoulos, the development of a ^6LiD irradiation capsule for the production of TD neutrons (13-15 MeV) in the reactor has been completed and a manuscript submitted for publication. The capsule produces more than 10^{10} TD n/cm²·sec in an irradiation volume of 1.3 cm³, and the conversion ratio and

fast flux profile have been carefully measured. The thermal and epithermal neutron flux profile in the reactor port where the capsule is used has also been determined. A critical review of previous measurements of the conversion ratio reveals that all of them suffer from one or more serious sources of error.

During the year we have had valuable opportunities to present our work and exchange information through a National Academy of Sciences lecture tour by R. W. Fink to Poland and West Germany and an invited paper at the American Nuclear Society meeting in San Francisco in November, 1977, and through an invited paper by J. L. Wood at the Symposium on Nuclei far from Stability at the American Chemical Society meeting in Chicago in August, 1977.

Following below are detailed descriptions of these activities.

2.0 NUCLEAR SPECTROSCOPY

2.1 Nuclear Systematics and Models

This year our effort has been devoted mainly to the application of models and systematics to decay scheme studies that have been completed (see Sect. 2.2 below) and are currently being prepared for publication. The completion of these decay schemes gives further strong support for our systematization of the odd-mass Au isotopes and provides some clues for a similar program in the odd-mass Hg isotopes: particularly the unique parity states originating from the $i_{13/2}$ neutron orbital.

One area where some completely new ideas have been generated is in our exploration of the nature of intruder states. We now believe that in addition to quadrupole pairing, a p-n interaction is very important and effectively produces a proton pair-neutron pair correlation. We have now reached some interim conclusions and following submittal of these results for publication, we will thoroughly pursue the development of nuclear models to describe this phenomenon,

as well as through suitable choices of experimental studies at UNISOR, some of which already are underway (see Sect. 2.3 below).

We have found the categorization of models adopted last year (namely: particle-core coupling and effective cores; the triaxial rotor model; the shell model and intruder states; and quadrupole pairing) to be of continuing suitability for the transition regions, but with an extension of the discussion of quadrupole pairing to include residual p-n interactions. These concepts (with the exception of residual p-n interactions) are treated in greater detail in last year's annual report, and what follows below is an updating of these ideas.

2.1.1 Particle-Core Coupling and Effective Cores

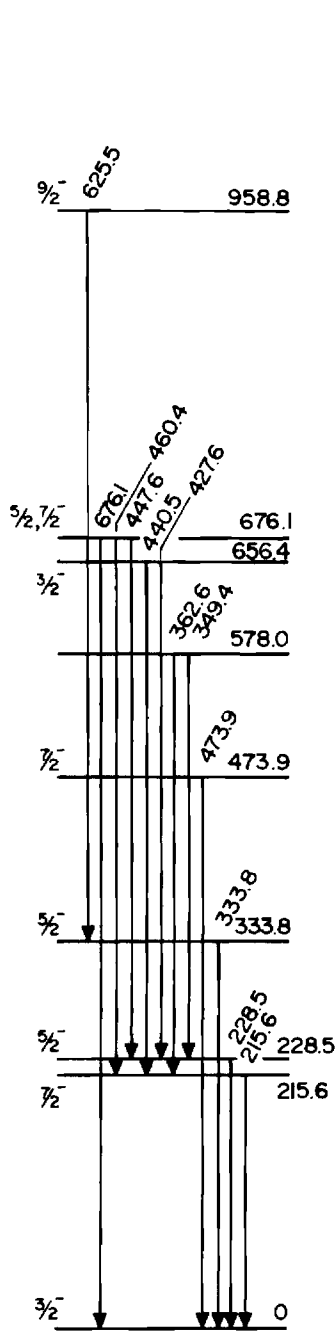
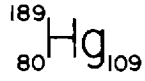
Our study of levels in ^{195}Hg (see Sect. 2.2.2) has located low-spin members of the $i_{13/2}$ band, and in comparing these states with their analogs in ^{197}Hg (where they have been located by nuclear reaction spectroscopy*), we

*P. Kemnitz, et al., Report ZfK-315 (Rossendorf, East Germany, 1976)

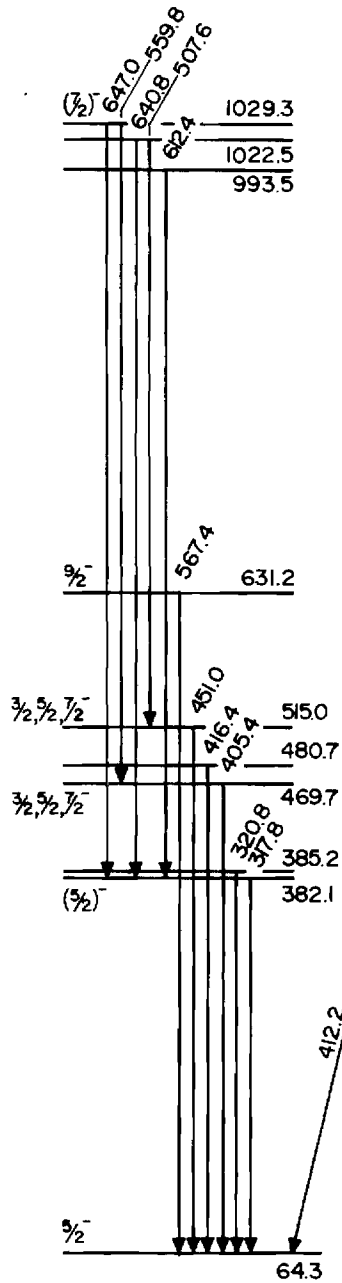
E. F. Zganjar, private communication, August (1977).

conclude that the $i_{13/2}$ neutron is essentially a hole-state and couples to a core effectively characterized by the neighboring double-even Hg nucleus with mass $A+1$. The low-spin members of the $i_{13/2}$ band in ^{195}Hg are only weakly populated in the decay of ^{195}Tl (0.35% per decay), hence the difficulty we are experiencing in the search for these states in the lighter odd-mass Hg isotopes.

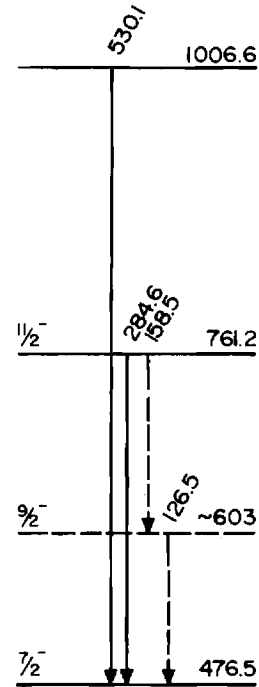
From the systematization of negative-parity states in the odd-mass Hg isotopes, we have tentative evidence in ^{189}Hg for a strongly deformed band (possibly built on the $7/2^-$ -[503] Nilsson state) at 476.5 keV above the weakly deformed ground state, as shown in Fig. 1. This needs to be confirmed by a lifetime measurement. If this interpretation is correct, the state is most probably a neutron-particle coupled to the deformed ^{188}Hg 0^+ core state at 825 keV, with a lowering of the deformed



$p_{3/2}$ BAND STRUCTURE
 $\beta \sim -0.17$
(OBLATE)



$f_{5/2}$ BAND STRUCTURE
 $\beta \sim -0.17$
(OBLATE)



PREDICTED DEFORMED BAND
 $\beta \sim +0.27$
(PROLATE)

minimum by 350 keV due to the presence of the odd neutron; this would be consistent with the $^{184}\text{Hg}/^{185}\text{Hg}$ pair where the lowering is 375 keV, and the $^{188}\text{Hg}/^{187}\text{Hg}$ pair, where we have some evidence for a lowering of 360 keV (see Sect. 2.3.4 below). This suggests a smooth trend in the single-neutron lowering of the deformed minimum. A detailed characterization of Nilsson states in this strongly deformed "second minimum" is one of the major goals of our continuing work in this region (see Sects. 2.3.1 and 2.3.4 below).

We have completed a detailed study of low-spin levels in ^{193}Au and this has enabled us to identify a band structure built on the lowest $1/2+$ state in $^{189,191,193}\text{Au}$ through systematics. The regularity of this band and those built on the lowest $3/2+$ and second $5/2+$ states suggests a rotational model rather than a vibrational one is applicable to this transitional region*. This result lends

*V. Paar, et al., Nucl. Phys. A284, 199 (1977)

strong support to a model for the positive-parity states in the odd-mass Au isotopes that couples the odd-proton quasiparticle to a weakly deformed rotating core. The choice between an Hg core with $A+1$, a Pt core with $A-1$, or some average of these two, has yet to be explored.

The work in progress on the decays of ^{187}Hg and ^{187}Au (see Sects. 2.3.1 and 2.3.3 below) reveals an immense complexity in the level schemes of ^{187}Au and ^{187}Pt . However, the detailed spectroscopy being conducted and the systematics clearly define states that are candidates for particles and holes coupled to weakly and strongly deformed cores.

2.1.2 Triaxial Rotor Model

We have carried our extensive calculations for an $i_{13/2}$ neutron

coupled to a rigid triaxial core^{a)} for a wide range of values of the Fermi energy and for nuclear shapes centered around that corresponding to a triaxial description of the doubly-even Hg isotopes. In general this model provides a good description of the high-spin members of the $i_{13/2}$ bands in the odd-mass Hg isotopes. However, we observe the low-spin $i_{13/2}$ band members to be substantially lower in energy in ^{195}Hg than theory predicts (e.g. $5/2+$: 668 keV above the band head vs. theory: 1100 keV), and a very similar behavior has been observed in ^{197}Hg (see Sect. 2.1.1). This failing is not adequately overcome by the use of a soft (variable moment of inertia) core^{b)} ($5/2+$ theory: 867 keV).

^a J. Meyer ter Vehn, Nucl. Phys. A249, 111, 141 (1975)

^b H. Toki and A. Faessler, Nucl. Phys. A253, 231 (1975)

We believe it will be necessary to extend the experimental $i_{13/2}$ band systematics to ^{189}Hg or even lighter Hg isotopes^{a)}, in order to see strong effects due to changes in the Fermi energy (see Sect. 2.1.1 above for a comment on the $i_{13/2}$ band population in the lighter Hg nuclei).

Our investigation of the applicability of the triaxial rotor model to the $h_{9/2}$ and $h_{11/2}$ collective bands in $^{189-193}\text{Au}$ is essentially completed and provides a useful base for systematics and for a simple description of the coupling of pure-j particles and holes to cores in this region. The identification of $h_{9/2}$ and $h_{11/2}$ collective states in $^{185,187}\text{Au}$ has benefited greatly from this investigation (see Sect. 2.3.1 below).

Cases, where a description using quasiparticles with mixed-j coupled to triaxial cores is necessary, must await the development of adequate computer codes. Thus, the low-spin negative-parity states in the odd-mass Hg and Pt nuclei and the low-spin positive-parity states in the odd-mass Au isotopes have not yet been described in any theoretical treatment based on a triaxial rotor model.

2.1.3 The Shell Model and Intruder States

Intruder states have received considerable attention in the literature in the past year; notably, in the $Z = 50$ closed shell region^{a,b)} and in the $Z = 82$ closed shell region^{b,c,d)}. We have concentrated on trying to

^a D. B. Fossah, et al., Phys. Rev. C15, 1732 (1977)

^b K. Heyde, et al., Phys. Lett. 64B, 135 (1976)

^c J. S. Dionisio, et al., J. Phys. (London) G2, L183 (1976); W. de Wiclawik, et al., G3, L57 (1977)

^d A. Goodman, preprint (1977)

understand the behavior of the $h_{9/2}$ state in the odd-mass Tl, Au, and Ir nuclei. From the $h_{9/2}$ systematics we argue that a description using single-particle potential energy surfaces^{b,c)} is wrong, since these models are unable to explain the very constant band spacings and hence unchanging deformation in the odd-mass Tl isotopes. By far the most dramatic discovery we have made is that the $h_{9/2}$ excitation energy relative to the ground state in Tl and Au nuclei is scaled in the ratio of 1:2, e.g.

<u>Nuclide</u>	<u>$E(h_{9/2}) - E(0)$ keV</u>	
197 _{Tl}	608.1	} 125.3
195 _{Tl}	482.8	
193 _{Au}	789.85	} $249.4 \times 1/2 = 124.7$
191 _{Au}	540.45	

and this continues even into the Ir isotopes in this particular sequence:

189 _{Ir}	563.7	} $377.5 \times 1/3 = 125.8$
187 _{Ir}	186.2	

It should be noted that this correspondence is between nuclei that differ by "alpha-particle" increments. We find further, at least in the case of the odd-mass Tl isotopes, that the $E(h_{9/2}) - E(0)$ energy difference is very well described by an empirical (parabolic) expression of the form

$$E(h_{9/2}) - E(0) = 312.4 + 3.00(A - 190.2) + 6.78(A - 190.2)^2 \text{ keV}$$

some possible explanations of these phenomena are discussed in Sect. 2.1.4 below.

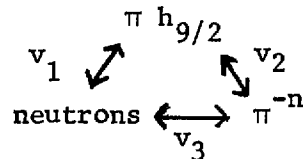
2.1.4 Pairing and Residual Interactions in the Shell Model of Heavy Nuclei

Evidence is beginning to accumulate in support of the idea that quadrupole pairing plays a major role in explaining the behavior of intruder states. Thus, recent ($^3\text{He},n$) studies^{a)} in the $Z = 50$ closed-shell region observed strongly populated 0^+ states at low energy. Such states can be explained only by pairing deformations^{b)}, such as would be produced by a residual quadrupole pairing force.

^a H. W. Fielding, et al., Nucl. Phys. A281, 389 (1977)

^b I. Ragnarsson and R. A. Broglia, Nucl. Phys. A263, 315 (1976)

From the phenomenology of the $h_{9/2}$ state in the $Z = 82$ region (see Sect. 2.1.3 above), we believe that in addition to a residual quadrupole pairing force (which acts between like nucleons), there is a proton-neutron force acting among the valence nucleons (for an $h_{9/2}$ configuration) in the following manner



where one valence proton is in the $h_{9/2}$ orbit and the rest occupy orbitals below the $Z = 82$ shell with \underline{n} holes left over ($n = 2$ for Tl, 4 for Au, 6 for Ir, etc.) and v_1 , v_2 , and v_3 are schematic interactions. The energy of the $h_{9/2}$ state relative to the ground state in the odd-mass Tl isotopes as a function of changing neutron number evidently cannot be described by v_2 , because it does not depend on the neutron number. We note that v_2 contains interactions of the particle-hole type as described by Blomqvist and others^{c)}. If v_1 were important, there would be

^c J. Blomqvist, Phys. Lett. 33B, 541 (1970)

J. S. Dionisio, et al., J. Phys. (London) G2, L183 (1976)

E. R. Flynn, and P. D. Kunz, Phys. Lett. 68B, 40 (1977)

a similarity among isotones, whereas the observed similarity is among nuclei differing by "alpha-particle" increments. The v_1 interaction can be regarded as the part of the

shell model potential for an $h_{9/2}$ proton generated by the neutrons, as described in the calculations of Goodman^{d)}. The interaction v_3 can account for the scaling between Tl, Au, and Ir, since $n = 2, 4, \text{ and } 6$, respectively. However, v_3 can be associated only with an $h_{9/2}$ proton configuration indirectly, and we argue that

^d A. Goodman, Preprint, 1977

quadrupole pairing results in the removal of the blocking effect when the odd-proton occupies the $h_{9/2}$ orbital, which then allows proton-hole pairs and neutron pairs to correlate. This is a completely new type of residual force for the shell model. We are currently exploring ways in which protons and neutrons can effectively interact through pairs by investigating in detail models for residual p-n forces in nuclei.

(J. L. Wood)

2.2 Completed Experimental Studies

2.2.1 Decay of Odd-Mass $^{189-193}\text{Hg}$ Isotopes

The studies of the decays of $^{189\text{m}}\text{Hg}$ (8.7 min), $^{189\text{g}}\text{Hg}$ (7.7 min), $^{191\text{m}}\text{Hg}$ (51 min), $^{191\text{g}}\text{Hg}$ (35 min), and $^{193\text{g}}\text{Hg}$ (4 h) to $^{189,191,193}\text{Au}$ daughters are in the process of being submitted for publication^{a,b,c)}. With the completion of these decay scheme studies, we have now finished the first stage of our investigation of the systematic features of structure in the odd-gold isotopes. The most dramatic findings revealed by our work have been published^{d,e)} already. The next stage will

^a "Decay of $^{189\text{m,g}}\text{Hg}$: Coupling of Particles and Holes," J. L. Wood, R. W. Fink, and UNISOR coauthors (to be published, 1977/78) [ORO-3346-176]

^b "Decay of $^{191\text{m,g}}\text{Hg}$ to ^{191}Au ," J. L. Wood, G. M. Gowdy, R. W. Fink, and UNISOR coauthors (to be published, 1977/78) [ORO-3346-177]

^c "Decay of ^{193}Hg (4 h) to ^{193}Au ," J. L. Wood, D. A. McClure, and R. W. Fink (to be published, 1977/78)

^d E. F. Zganjar, J. L. Wood, R. W. Fink, and other UNISOR coauthors, Phys. Lett. 58B, 159 (1975)

^e J. L. Wood, R. W. Fink, E. F. Zganjar, and J. Meyer ter Vehn, Phys. Rev. C14, 682 (1976)

be the application of these systematics to understanding the appearance of strongly deformed states in $^{185,187}\text{Au}$ (see Sect. 2.3.1 below), a detailed study of nuclear models suitable for describing the various modes of excitation observed in the odd-Au isotopes, and a search for new modes of excitation in ^{199}Au (see Sect. 2.3.6 below).

2.2.2 Decay of Odd-Mass $^{189-197}\text{Tl}$ Isotopes

The studies of the decays of $^{189\text{m}}\text{Tl}$ (1.4 min), $^{191\text{m}}\text{Tl}$ (5.5 min), $^{193\text{m}}\text{Tl}$ (2.1 min), $^{193\text{g}}\text{Tl}$ (21 min), ^{195}Tl (1.2 h), and ^{197}Tl (2.8 h) to $^{189,191,193,195,197}\text{Hg}$ daughters also are in the process of being submitted for publication^{f,g,h,i,j}. These

^f "Decay of ^{189}Tl (1.4 min) to ^{189}Hg ," E. F. Zganjar, J. L. Wood, G. M. Gowdy, R. W. Fink, and other UNISOR coauthors, (to be published, 1977/78)

^g "Decay of ^{191}Tl (5.5 min) to ^{191}Hg ," G. M. Gowdy, J. L. Wood, R. W. Fink, and other UNISOR coauthors (to be published, 1977/78)

^h "Decay of $^{193\text{m,g}}\text{Tl}$ to ^{193}Hg ," J. L. Wood, G. M. Gowdy, R. W. Fink, and other UNISOR coauthors (to be published, 1977/78)

ⁱ "Decay of ^{195}Tl (1.2 h) to ^{195}Hg ," G. M. Gowdy, J. L. Wood, and R. W. Fink (to be published, 1977/78)

^j "Decay of ^{197}Tl (2.8 h) to ^{197}Hg ," R. A. Braga, J. L. Wood, G. M. Gowdy, and R. W. Fink, (to be published, 1977/78)

decay scheme studies provide an immense amount of new information on the structure of the odd-Hg isotopes. At present it is not possible to identify systematic features to the extent shown by the odd-Au isotopes: the foremost need in the odd-Hg isotopes is a substantial development of suitable models (such as a "mixed-j triaxial rotor" treatment). However, as discussed in Sect. 2.1.1 above, our systematization of the odd-Hg isotopes has been sufficient to locate deformed states in ^{189}Hg and ^{187}Hg (see Sect. 2.3.4 below).

2.2.3 Decay of $^{197\text{m,g}}\text{Pb}$

The studies of the decay of $^{197\text{m}}\text{Pb}$ (42 min) and $^{197\text{g}}\text{Pb}$ (≈ 11 min) to ^{197}Tl are, except for some questions about the half-life of the ^{197}Pb ground state, ready to be submitted for publication. These decay schemes have provided a very detailed test of the triaxial rotor model for an $h_{9/2}$ particle coupled to an even-Hg core. This work is being coordinated by Prof. L. L. Riedinger, University of Tennessee, with participation by the Georgia Tech group.

2.3 Current Experimental Investigations

2.3.1 Decay of $^{185,187}\text{Hg}$ Isotopes

As a result of our findings in the initial study of ^{187}Hg (2.2 min) decay to ^{187}Au made two years ago, we have begun a restudy of this extremely complex decay in much greater detail: this investigation now constitutes a major part of the Ph.D. thesis work of Mr. M. Grimm, who is at UNISOR under an ORAU fellowship. The prime motivation for this restudy is the evidence we obtained indicating the population of strongly deformed states in ^{187}Au . So far we have taken $\gamma\gamma$ -t coincidence and γ -ray multiscaling data following $^{180}\text{W}(^{14}\text{N},7n)$ and $^{180}\text{W}(^{14}\text{N},p6n)$ reactions with 150-180 MeV $^{14}\text{N}^{+5}$ ions. The use of a W_2O_3 target enriched to 92.96% in ^{180}W and 6 shifts of beam time enabled us to obtain five times better statistics than in the earlier $\gamma\gamma$ -t experiment (the statistical quality of these new data is comparable to the best ever achieved at UNISOR, some eight mass units closer to the line of beta stability!). Based on our systematics for the odd-Au isotopes, we interpret many groups of γ -rays to be due to band structures lying at low energy, resulting from new degrees of freedom (strongly deformed structures) appearing at low energy in ^{187}Au . With the resumption of operations at ORIC, we will be completing this study with conversion electron studies in the near future.

We also are studying the decay of ^{185}Hg (51 sec, 21 sec) to ^{185}Au following the $^{180}\text{W}(^{14}\text{N},p8n)$ reaction with 150-180 MeV $^{14}\text{N}^{+5}$ ions. The nucleus ^{185}Hg has a strongly deformed ground state ($T_{1/2} = 51$ sec), based on optical pumping measurements^{a)} of its mean square charge radius. The construction of a level

^a J. Bonn, et al., Z. Physik A276, 203 (1976)

scheme for ^{185}Au has been facilitated greatly by in-beam γ -ray and ce^- spectroscopy in the reaction $^{169}\text{Tm}(^{20}\text{Ne},4n)$ which has been carried out by Prof. L. L. Riedinger, Univ. of Tennessee, and E. F. Zganjar, L.S.U., specifically to help understand the

^{185}Hg decay scheme. Conversion electron measurements are planned for the near future. Because of the complexity of this decay, it is possible that it will be fully elucidated only when heavier ions (and lighter compound nuclei) become available with high beam currents from the new heavy-ion folded tandem accelerator at Oak Ridge. This decay study is being done in collaboration with E. F. Zganjar (LSU).

2.3.2 Decay of $^{201m,g}\text{Po}$ and $^{201m,g}\text{Bi}$ Isobars

An analysis of the decay of $^{201m,g}\text{Po}$ (9, 14 min) and $^{201m,g}\text{Bi}$ (59 min, 1.8 h) isobars is proceeding under the coordination of Dr. W. R. Western. The activity is produced at UNISOR by bombarding natural Ir with 113 MeV ^{14}N ions, and the data acquired include γ and ce^- singles, $\gamma\gamma^-$ and $ce^-\gamma$ coincidence, and γ and ce^- multispectra. Several previously unreported transitions have been observed in the decay of the $^{201m,g}\text{Po}$ isomers. The reason we observe both ^{201}Po isomers is that the high-spin upper state, produced almost exclusively in the heavy ion reaction, feeds the lower-spin ground state via an isomeric cascade. A careful growth-decay curve will be attempted, in order to establish the genetic relationships among the 9 and 14 min ^{201}Po isomers and the 59 min and 1.8 h ^{201}Bi daughters.

This work is part of a UNISOR effort to investigate the systematics of the light $Z = 83$ nuclei. It is of particular interest to study the coupling of the single-particle or hole states to the even-even Pb or Po core. The resulting coupling schemes will be compared to the $Z = 81$ proton-hole systems. An attempt will be made to identify the $s_{1/2}$, $d_{3/2}$, and $h_{11/2}$ intruder states, so that the systematics of these states can be investigated..

A preliminary report on the ^{201}Po decays was presented at the American Physical Society meeting at Rochester, N.Y. in October, 1977. (W. R. Western)

2.3.3 Decay of Odd-Mass $^{185-189}\text{Au}$ Isotopes

In the investigation of the $^{185,187}\text{Hg}$ decays described above, we have, by using longer source collection times, optimized data acquisition conditions

for the study of the decays of ^{185}Au (4 min) and ^{187}Au (8 min) to ^{185}Pt and ^{187}Pt , respectively. Both of these studies await conversion electron measurements. The ^{187}Au decay constitutes a part of the Ph.D. thesis of Mr. M. Grimm. Our investigation of the decay of ^{189}Au (4 min, 28 min) still awaits technical development at UNISOR: either the ability to make ce^- measurements in combination with a He gas-jet transport system, or on-line mass separation of Au isotopes with high efficiency. The latter possibility shows considerable promise. The main goal of these investigations is the characterization of the $i_{13/2}$ band in the light Pt isotopes, where it has been reported^{a)} that the high-spin band members support a shape transition

^a C. Bourgeois, et al., Cargese Conf. Proceedings, CERN-76-13 (1976); p. 456

between ^{187}Pt and ^{185}Pt . Besides confirming this, the characterization of the $i_{13/2}$ band in this region should reveal the role played by the Fermi energy in the triaxial rotor model of Meyer ter Vehn (see Sect. 2.1 above).

2.3.4 Decay of $^{185,187}\text{Tl}$ Isotopes

Our investigation of the decays of ^{187}Tl (18 sec, 54 sec) and ^{185}Tl (1.7 sec) to ^{187}Hg and ^{185}Hg , respectively, will continue when we can achieve higher production rates of these isotopes (probably by means of heavier ions when the new heavy-ion folded tandem accelerator is operational). Our results so far have been sufficient to locate the $h_{9/2}$ isomer in these isotopes^{b)} and to reveal candidates for deformed states in ^{187}Hg (see Sect. 2.1.1 above).

^b A. G. Schmidt, G. M. Gowdy, J. L. Wood, R. W. Fink, and other UNISOR coauthors, Phys. Lett. 66B, 133 (1977)

2.3.5 Nuclear Lifetime Measurements

Our program of nuclear lifetime measurements has proceeded in two directions. The multiple time analysis (MTA) computer-based system for measurement of lifetimes of nuclear levels in the range of 10 μ sec to 1 sec has become operational

at UNISOR. However, owing to the extended down-period of ORIC, as of this writing (September, 1977), no measurements utilizing this system have been made. However, an extensive test of the system has been undertaken using a ^{207}Bi source. A value of 0.8 ± 0.2 sec was obtained for the lifetime of the 1633 keV level in ^{207}Pb . This is in excellent agreement with the adopted value of 0.8 sec. A significant aspect of these tests was that the value obtained by the MTA concept was the result of data accumulation times as short as 1 hour, whereas conventional techniques would have required much longer counting periods, in order to achieve results with comparable accuracy. Although data acquisition time is short, data analysis requires extensive computer time, making the use of the Georgia Tech CDC Cyber 74 computer highly impractical. Therefore, a code for our Nuclear Data ND-4420 system was written to analyze the UNISOR MTA data (see Sect. 5.3.3). (R. A. Braga)

The measurement of nuclear lifetimes employing delayed coincidence techniques, having been extended last year into the nanosec region with state-of-the-art timing modules, has been further extended into the sub-nanosec region with the recent acquisition of a plastic scintillation spectrometer. A system, consisting of the plastic scintillator, Ge(Li) detector, and timing modules, has been tested and preliminary measurements of the lifetime of states in ^{109}Ag believed to be members of the $g_{7/2}$ intruder band have been performed. These levels are populated in the decay of 13.43 h ^{109}Pd , sources of which were prepared by the enriched $^{108}\text{Pd}(n,\gamma)$ reaction in the Georgia Tech Research Reactor. Since less than 2% of all decays populate the levels of interest, more extensive measurements are in progress.

(R. A. Braga)

2.3.6 Other Work

Our investigation of the decay of 31 min ^{199}Pt to ^{199}Au following thermal neutron activation of enriched ^{198}Pt samples in the Georgia Tech Research Reactor will continue when a new supply of enriched ^{198}Pt becomes available from Oak Ridge, whose supply is temporarily exhausted.

We have discontinued our study of the decay of 12 min ^{151}Nd to ^{151}Pm , reported last year, because we learned that a similar study is being made at the Lawrence Livermore Laboratory. (C. Papanicolopoulos)

The continuation of the study of the decay of ^{191}Pb (2.0 min) to ^{191}Tl awaits technical development at UNISOR, most notably the operation of a high-temperature ion source without threat of vaporization of our expensive enriched ^{180}W targets.

2.4 International Comparison of ^{152}Eu Calibration Standards

During the year our group participated in the international comparison of γ -ray emission-rate measurements on ^{152}Eu sources, which was organized by the Working Group on Alpha-, Beta-, Gamma-ray Spectrometry of the International Committee for Radionuclide Metrology (ICRM) under the chairmanship of Dr. K. Debertin (Physikalisch-Technische Bundesanstalt, Braunschweig, West Germany) and in which the National Bureau of Standards (Radioactivity Section) represents the USA.

This study involved a precision efficiency calibration of our Princeton Gamma-Tech 6% Ge(Li) detector (resolution: 1.66 keV FWHM at 1332 keV) prior to the determination of the γ -ray emission probabilities of the ^{152}Eu source, which was sent to us from West Germany by way of the National Bureau of Standards, and which is being donated to us on completion of the measurements. The efficiency calibration was performed using a NBS mixed γ -ray point source No. SRM-4215D (September 1, 1976) and by taking advantage of 1:1 $\gamma\gamma$ multiple cascades in other radioactive sources. The mixed γ -ray standard is calibrated as to emission rate and contained the following radionuclides: ^{109}Cd (88.037 keV), ^{57}Co (122.063 keV), ^{139}Ce (165.853 keV), ^{203}Hg (279.188 keV), ^{113}Sn (391.688 keV), ^{85}Sr (514.996 keV), ^{137}Cs (661.638 keV), ^{88}Y (898.021, 1836.074 keV), ^{60}Co (1173.208, 1332.491 keV). The use of the 1:1 multiple γ -ray cascades in ^{94}Nb , ^{46}Sc , $^{90\text{m}}\text{Y}$, and $^{180\text{m}}\text{Hf}$ represents a method of determining the relative efficiency which is completely independent of absolute calibration standards. These cascades

(corrected for conversion) provided additional data points in energy regions lacking absolute standard lines and thus provide a much improved relative efficiency curve, particularly between 100 and 300 keV where curvature exists that is otherwise not measured. The ^{46}Sc , $^{90\text{m}}\text{Y}$, and $^{180\text{m}}\text{Hf}$ activities were produced by irradiations in the Georgia Tech Research Reactor. A "reduced" representation of the efficiency curve obtained at 10 cm source-to-detector distance is shown in Fig. 2a. The efficiency ϵ is divided by $\epsilon_0 = aE^{-b}$, where a and b are fitting parameters based on the individual Ge(Li) detector size and characteristics, and the ratio ϵ/ϵ_0 is plotted vs. energy E .

Each member of our group applied different peak evaluation methods towards the analysis of individually obtained calibration and ^{152}Eu data. These procedures varied from a manual subtraction of continuum areas to a computer-fit of a skewed-Gaussian line shape. Measurements were made by all members of our group at a source-to-detector distance of 10 cm as well as by individual members at source-to-detector distances of 5, 12, 15, and 20 cm. A comparison of the results as a function of source-to-detector distance permitted an evaluation of corrections for summing effects. Within the statistical quality of our data (1%), no summing effects were observed at 10 cm. This comparison also resulted in the observation of the failure of our Nuclear Data ND-4420 system to compensate correctly for deadtime losses. An error of approximately 20% in the emission rate was found with the dissimilar counting rates obtained from the calibration and the ^{152}Eu sources. This failure to correct for deadtime losses appears to be the result of an inadequate design of the livetime/real time clock system. We are now attempting to correct the instrument for this problem.

The ^{152}Eu γ -ray emission probabilities obtained by our group for selected lines are given in Table 1, along with the values from the "world's best data" set,

resulting from the measurements by nine selected participants (out of about 30) of the ^{152}Eu γ -ray emission probabilities, the Georgia Tech group being selected as one of the nine. The justification for our selection (by PTB, Braunschweig, West Germany) as one of the "world's best" is shown in a plot of the relative deviations of our results from the weighted mean vs. line number (Fig. 2 b).

A preliminary summary of the results of this international comparison on ^{152}Eu has been compiled by K. Debertin (PTB, Braunschweig, West Germany). Among the conclusions drawn are: "The simple log-log plot of efficiency vs. energy is only a very rough approximation" and "with state-of-the-art Ge(Li) spectrometers, γ -ray emission rates can be determined to an accuracy of about 1%." From our participation in this study, we have concluded that to obtain emission rates accurate to 1%, extreme care must be taken in selecting efficiency calibration standards (i.e., 1:1 cascades) and in interpolating between calibration points. We have also concluded that relative emission probabilities are independent of peak evaluation methods, provided the same method and evaluation criteria are applied to both the standards and the source.

Table 1 - Comparison of Georgia Tech Results on ^{152}Eu with "World's Best" Data ^{a)}			
Line No.	E(keV)	Gamma-ray Emission Probability	
		Georgia Tech	"World's Best"
1	121.8	135.7	136.0
2	244.7	35.5	35.9
3	344.3	128.9	127.7
4	411.1	10.46	10.71
5	444.0	14.68	14.92
6	778.9	62.4	62.1
7	964.0	69.6	70.0
8	1085.8	48.9	48.8
9	1112.1	64.3	64.8
10	1408.1	100.0	100.0

^a Taken from the report of K. Debertin, PTB, Braunschweig, West Germany, August, 1977

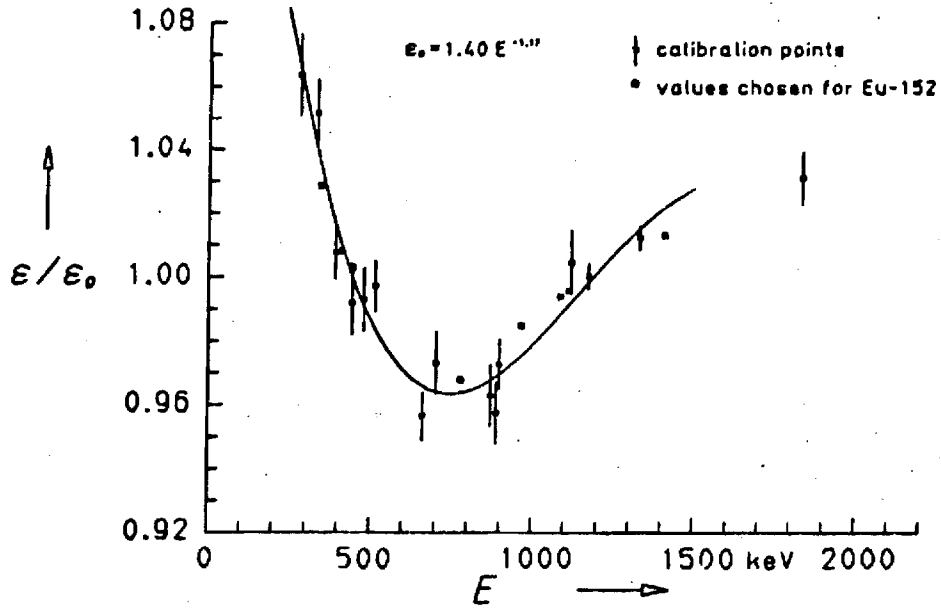


Fig. 2a

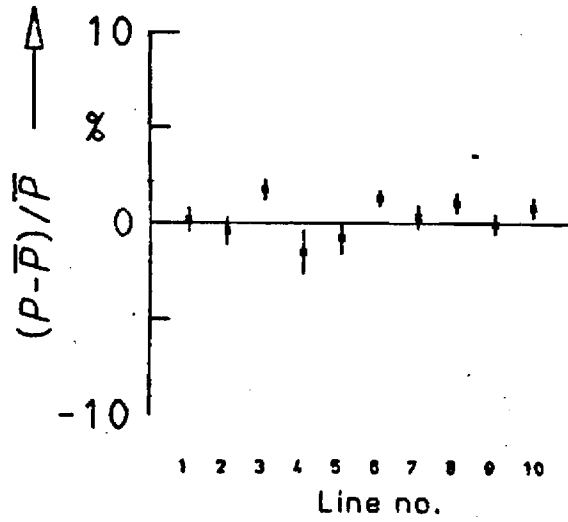


Fig. 2b

3.0 FAST NEUTRON RESEARCH

3.1 A ${}^6\text{LiD}$ Irradiation Capsule for Producing 14 ± 2 MeV Neutrons in the Reactor

As part of the Ph.D. thesis work of Mr. C. Papanicolopoulos, a small double-walled zirconium irradiation capsule containing 95.56% enriched ${}^6\text{LiD}$ was tested in the Georgia Tech Research Reactor in an incident neutron flux of 4.65×10^{13} n/cm².sec at 1 MW power. The ${}^6\text{Li}(n,t){}^4\text{He}$ - ${}^2\text{H}(t,n){}^4\text{He}$ reaction sequence produced a 14 ± 2 MeV flux of 4.48×10^{10} n/cm².sec inside the approximately 1.3 cm³ irradiation volume, indicating for this design an effective conversion ratio of 9.6×10^{-4} , equivalent to a thermal conversion ratio of 2.46×10^{-3} . The fast neutron flux present inside the irradiation volume was monitored by various (n,2n), (n, α), and (n,p) reactions having thresholds from 1 to 14 MeV, and the incident flux of thermal and epithermal neutrons was monitored at various locations over the exterior surface of the capsule by the ${}^{58}\text{Co}(n,\gamma){}^{60}\text{Co}$ reaction. In addition, the In+Cd and Cd ratios were measured without the capsule in the beamport, in order to determine the approximate energy profile of the thermal and epithermal flux of reactor neutrons. The temperature rise in the capsule as a function of reactor power level due to heat generated in the ${}^6\text{LiD}$ layer was measured in a non-water-cooled location, indicating a rise to 350°C at a power level of only 300 KW in a few minutes time, so that the maximum flux (at 1-5 MW power) can be produced only with water cooling of the capsule. The presence of a large flux of epithermal neutrons above the Cd cutoff (0.4 eV) gives rise to appreciable (n, γ) reactions; to remove most of this epithermal flux requires a relatively thick shield of boron nitride inside the ${}^6\text{LiD}$ layer. Some design characteristics of a larger capsule which can accommodate both the thicker boron nitride shielding and water cooling channels are discussed. Possible applications include the determination of 14 ± 2 MeV neutron cross sections leading to long-lived activation products, production of relatively long-lived radioactive sources, preparation of short-lived, positron-emitting (n,2n) nuclides for nuclear medicine, long-term materials testing, and neutron activation analysis with

14 ± 2 MeV neutrons. Short-lived radioactive samples can be handled by use of a compressed air rabbit to transport the specimen from the ${}^6\text{LiD}$ capsule without having to remove the apparatus from the reactor until a later time. A manuscript has been submitted for publication^{a)}. The design of the capsule is shown in Fig. 3 and

^a C. Papanicolopoulos and R. W. Fink, "Production of 14 ± 2 MeV Neutrons in a Reactor with an Enriched ${}^6\text{LiD}$ Irradiation Capsule," Nuclear Instr. & Meth. (submitted, September, 1977) [ORO-3346-211]

described in detail in the manuscript^{a)}. A photograph of the internal parts is shown in Fig. 4. The measured neutron energy-dependent flux profile is shown in Fig. 5, where the solid line is the result with the capsule in place in the water-cooled beamport H-4 of the Georgia Tech Research Reactor, and the dashed line is the flux profile in the same location, but with the capsule removed. In addition, the thermal and epithermal flux was measured by the ${}^{59}\text{Co}(n,\gamma){}^{60}\text{Co}$ monitoring reaction with the Cd and In + Cd ratio method. The following values were obtained^{a)}: From 0.0253 to 0.4 eV, $\Phi = 3.2 \times 10^{13}$ n/cm².sec; from 0.4 to 1.46 eV, 8×10^{12} n/cm².sec; at 132 eV, 6.5×10^{12} n/cm².sec; and at 330 eV (in the capsule), 5.0×10^{12} n/cm².sec. Thus, this beamport position in our reactor has an epithermal and resonance energy neutron flux almost equal to the "thermal" neutron flux below 0.4 eV. The implications of this are discussed in detail in the manuscript^{a)}.

3.2 Use of the ${}^6\text{LiD}$ Capsule for Decay Study of ${}^{173}\text{Tm}$

As a test of the ability of our ${}^6\text{LiD}$ capsule to produce radionuclides by 14 ± 2 MeV neutron-induced reactions, we plan to study the decay of 8 hour ${}^{173}\text{Tm}$ to ${}^{173}\text{Yb}$. Enriched targets of ${}^{173}\text{Yb}_2\text{O}_3$ will be irradiated in the capsule to produce the ${}^{173}\text{Yb}(n,p){}^{173}\text{Tm}$ reaction, expected to have a cross section of a few millibarns at 14 ± 2 MeV. A complete search will be made for the low-spin states in ${}^{173}\text{Yb}$, particularly for possible vibrational modes coupled to the low-lying Nilsson states. The $J = 1/2+$ ground state configuration of ${}^{173}\text{Tm}$ should be favorable for

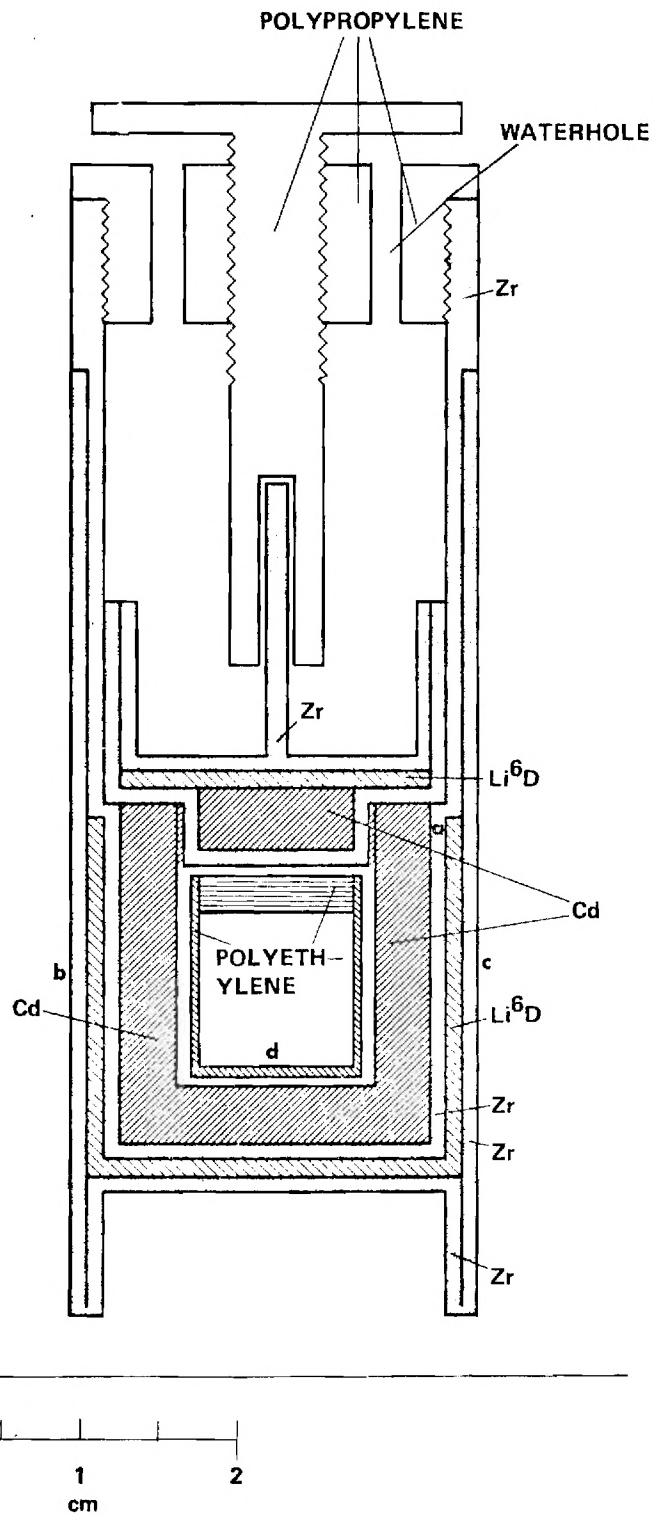


Fig. 3 - Schematic cross section of the ⁶LiD irradiation capsule.

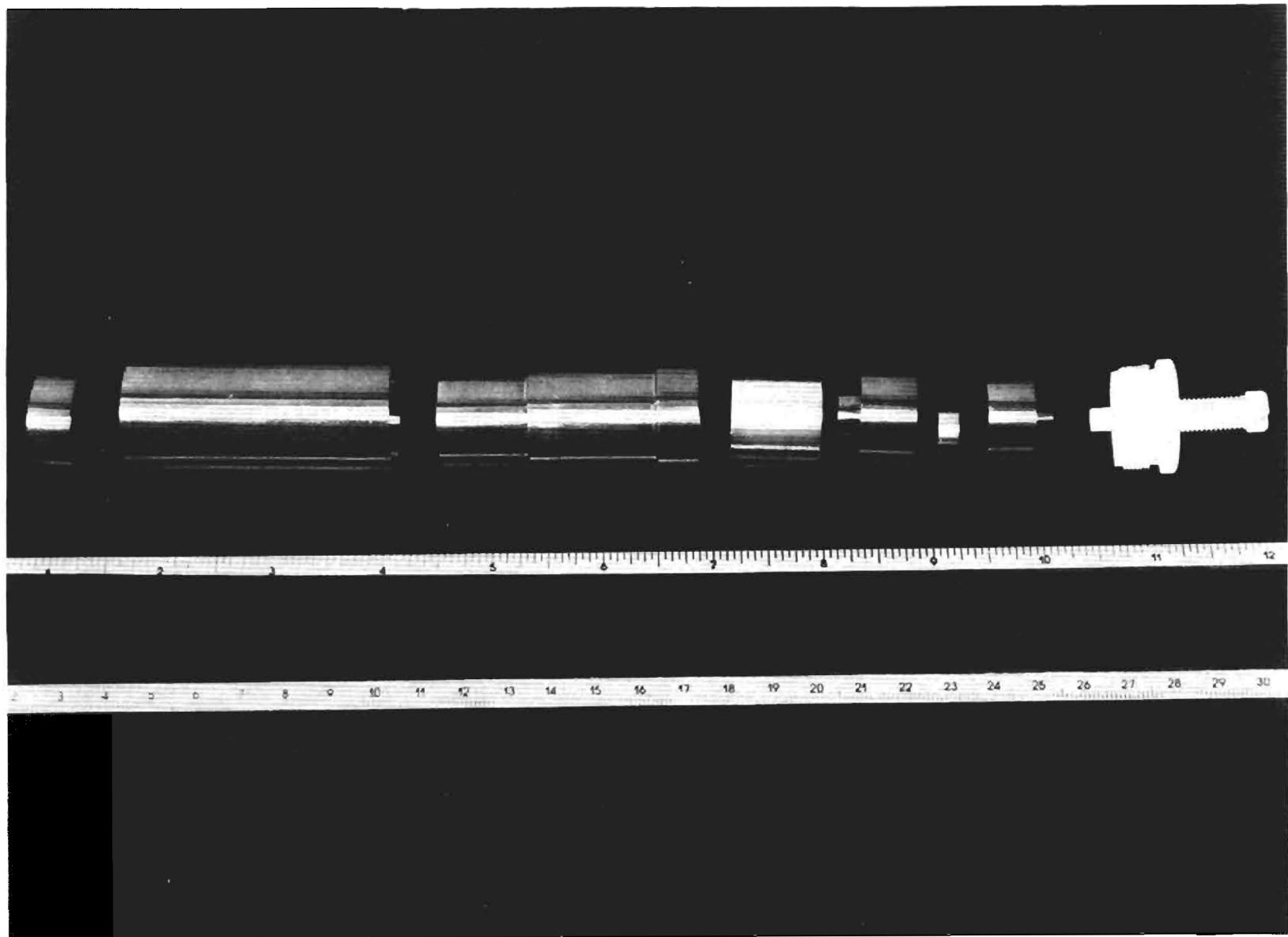


Figure 4. Exploded photographic view of the 6LID irradiation capsule.

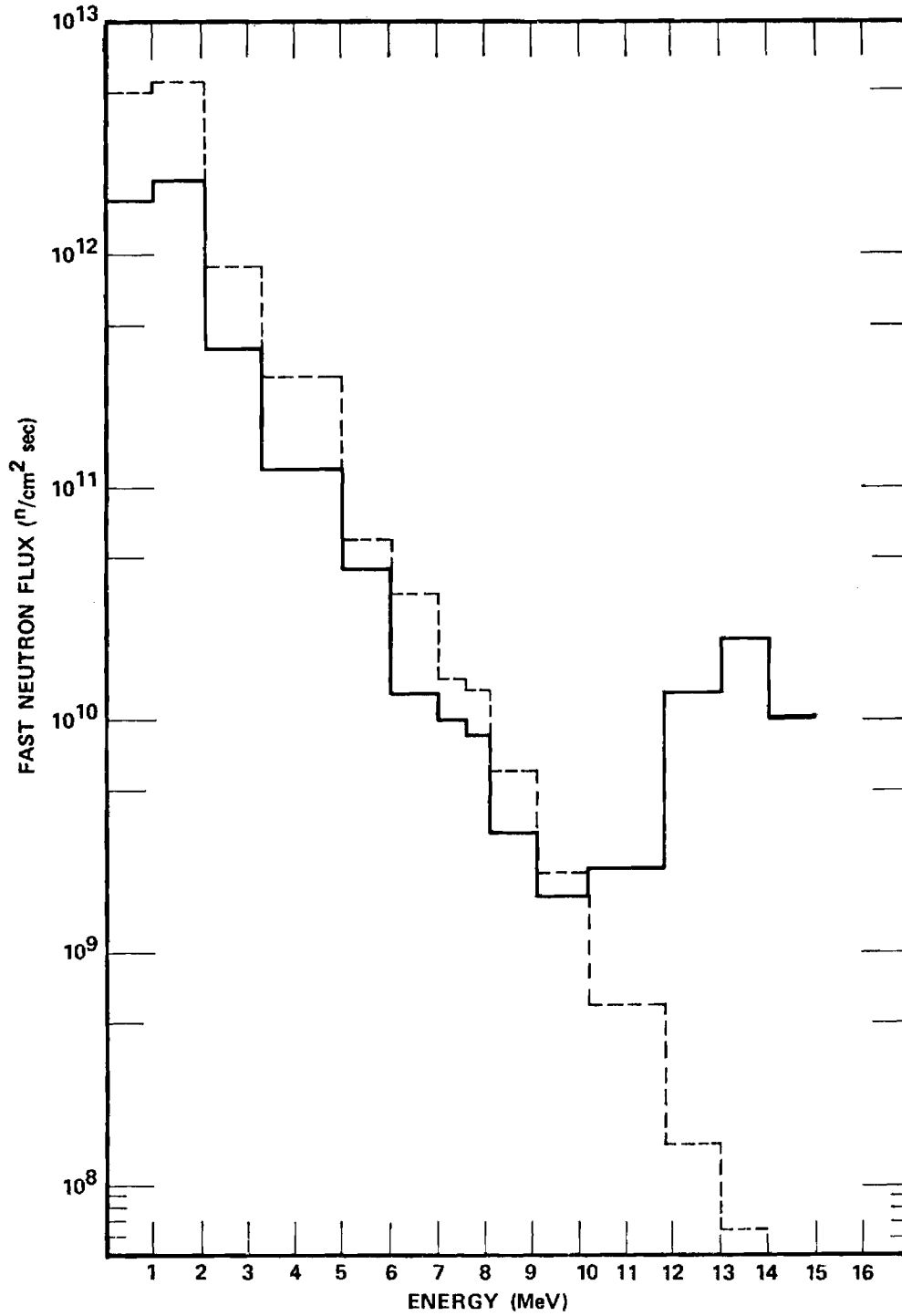


Fig 5 - The energy-dependent neutron flux profile in the H-4 beamport of the Georgia Tech Research Reactor: Solid Curve: With the ⁶LiD capsule in place; Dashed Curve: With the capsule removed.

populating low-spin states up to about 1200 keV, since $Q_{EC} = 1320 \pm 30$ keV. There is no recent study of this decay, and the most recent information indicates the population of only two excited states, at 399 and 462 keV in ^{173}Yb . (C. Papanicolopoulos)

4.0 X-RAYS FROM RADIOACTIVE SOURCES

4.1 Tables for Handbook of Spectroscopy, 2nd Ed.

A revised set of tables of x-ray and Coster-Kronig yields has been prepared for publication in the forthcoming new edition of Handbook of Spectroscopy^{a)}. This is an updating of the original publication^{b)}.

^a R. W. Fink and P. V. Rao, "Tables of Experimental Values of X-ray Fluorescence and Coster-Kronig Yields for the K, L, and M Shells," in Handbook of Spectroscopy, 2nd Ed., edited by J. W. Robinson (CRC Publishing Co., Cleveland, Ohio, 1978).

^b R. W. Fink and P. V. Rao, *ibid*, 1st Edition (CRC Publishing Co., Cleveland, Ohio, Vol. 1, 1974); pp. 219-229

4.2 Experimental Measurement of the L-Subshell X-ray Fluorescence and Coster-Kronig Transition Yields at Z = 67

A measurement of the L-subshell x-ray fluorescence yields ω_2 , ω_3 , and the Coster-Kronig transition probability f_{23} for $Z = 67$ is in progress from the decay of 10.4 hour ^{165}Er . Three-parameter coincidence measurements are being performed with high resolution Si(Li) and intrinsic Ge planar x-ray detectors on sources of ^{165}Er , which are prepared via the (n,γ) reaction on Er_2O_3 enriched to $\geq 67\%$ in mass 164 in the Georgia Tech Research Reactor. A description of this problem can be found in last year's Renewal Proposal, and it constitutes an introductory thesis problem for Mr. Bruce Gnade.

(Bruce Gnade and R. A. Braga)

5.0 MISCELLANEOUS TOPICS

5.1 Advisory Board Activities for Handbook of Spectroscopy, 2nd Ed.

Dr. R. W. Fink has been serving on the international advisory board for the forthcoming edition of the Handbook of Spectroscopy, 2nd ed. (CRC Publishing Company, Cleveland, Ohio, 1978), and has arranged for the inclusion of nuclear chapters suitable for reference in the field of neutron activation analysis. He has been responsible for arranging for a chapter on 14 MeV neutron activation cross sections for fast neutron activation analysis by Dr. S. M. Qaim, and for a chapter on principal gamma rays arranged by increasing energy by Dr. G. Erdtmann, both of the Kernforschungsanlage Jülich, West Germany.

5.2 Tables of Thermal Neutron Cross Sections

In connection with the above handbook, Dr. R. W. Fink has compiled a table of thermal (2200 m/sec and Maxwellian) neutron cross sections and half-lives and radioactive products of thermal neutron activation reactions^a). This will constitute a chapter in the handbook (Vol. 3) which will appear in 1978.

^a R. W. Fink, "Thermal Neutron Reaction Cross Sections," in J. W. Robinson, editor, Handbook of Spectroscopy, 2nd Ed, (CRC Publishing Co., Cleveland, Ohio, 1978)

5.3 Development of Computer Programs

Efficient and effective computer codes are essential to our nuclear spectroscopy studies, owing to the immense quantity of data and transitions coming from UNISOR runs. Part of the time available during the UNISOR-ORIC shutdown during 1977 has been used to improve the computer analysis capabilities on our Georgia Tech computers (CDC-Cyber 74, Nuclear Data ND-4420, and PDP-15). These improvements have been made in three directions. The first is adapting codes obtained from the Ames-ERDA laboratory spectroscopy group to our CDC Cyber 74 system. The second is the development of a new more efficient approach and codes for the analysis of coincidence data using the CDC-Cyber system. The

third direction is the development of codes to analyze data on small computers, specifically the Nuclear Data 4420 system in our laboratory, and the PDP-15 system in the Georgia Tech Nuclear Research Center.

5.3.1 Codes for the Analysis of Singles Data: SKEWGAUS and PEAKFIND

Two computer codes for the analysis of singles data, SKEWGAUS and PEAKFIND, have been adapted and modified for use on the CDC Cyber 74 system by Dr. W. R. Western. These two codes were developed by the nuclear spectroscopy group at the Ames-ERDA Laboratory. They are used to fit peaks in the spectra and determine areas and centroids. The user has more options and more control of the fitting process than is possible with SAMPO, which was used previously. There are two types of background functions, additional peak shape parameters, and up to 13 peaks may be included in a fit region with the SKEWGAUS code. The SKEWGAUS code requires the user to specify which parameters are fixed, free to vary, or constrained to vary as corresponding parameters in some of the other peaks.

Another code from the Ames group which will be adapted to the CDC Cyber system is a code to calculate level energies and feedings. A least squares fit of the energy levels using the gamma transition energies and placements is performed and the beta feedings to the levels is determined from an intensity balance calculation.

5.3.2 New Codes for Coincidence Data: PRESCN and GATESCN

A new approach for the construction of coincidence spectra has been developed by Dr. W. R. Western for use on the CDC Cyber system. Construction of coincidence spectra requires large amounts of both fast storage space and tape I/O. The approach developed is to presort the events with a code which does not require a large amount of core memory for storage. The actual construction of the spectra can be done from these presorted output files which are much smaller than the original data files, since almost every event is used.

The codes are written in CDC FORTRAN and contain programming to use efficiently the 60-bit word size of CDC system and asynchronous tape reading for more efficient use of time. The PRESCN code can presort data for over 100 gates, while using less than 40K words of core, and the GATESCN code with overlays can construct 48 spectra in less than 60K words of core. A manuscript describing these codes will be submitted to Nuclear Instruments and Methods.

5.3.3 Codes for the Nuclear Data ND-4420 and the PDP-15 Computers

The Multiple Time Analysis technique for determining lifetimes of nuclear levels requires a large amount of computation for each event accepted, but little array space is required. Excessive time is required to process these data on the CDC Cyber system. The development of the PRESCN code provides a means to read Tennecomp tapes from UNISOR and create a small output tape of accepted start and stop events which can be easily read by the nuclear data ND-4420 system in our laboratory. Dr. R. A. Braga has created a subprogram from existing nuclear data codes to read magnetic tapes and the development of the main code (also written in assembler language) should be implemented shortly.

During the latter part of the reporting period, we have obtained access to a PDP-15 computer located on campus. This system contains a TV display and disk pack and is suitable for interactive analysis of spectra. The SKEWGAUS code described above is being adapted and implemented for the PDP-15 by Mr. C. Papanicolopoulos and Dr. W. R. Western.

6.0 EQUIPMENT ADDED DURING 1977

With the extension of our program of nuclear lifetime measurements to the subnanosec region (see Sect. 2.3.5), we have purchased a Nuclear Enterprises plastic scintillation spectrometer, consisting of a plastic scintillator, a RCA 8575 photomultiplier tube, and tube case containing the preamplifier and voltage divider network in a demountable assembly. Two interchangeable plastic scintillators were purchased: a 2.0-inch dia x 1.0 inch thick Pilot B with 5% lead-loading for increased resolution, and a 2.0-inch dia x 1.0-inch thick NE-111 for ultrafast timing. An additional Canberra Model 1412 Research Amplifier was purchased for use with this plastic scintillation spectrometer.

(R. A. Braga)

Following the departure of Dr. D. A. McClure from the physics faculty, we have transferred the 80-character fast line printer, purchased in 1976, from the physics building to our Applied Digital Data System, Model 580 CRT Computer Terminal in our laboratory for rapid printout of hard copy from the central CDC-Cyber 74 computer.

(W. R. Western and R. A. Braga)

7.0 PERSONNEL

Senior Staff:

Dr. R. W. Fink, Professor & Senior Investigator (1/4 time ERDA)

Dr. J. L. Wood, Senior Research Associate
(Oct. 1, 1972 - Present; full-time ERDA, 12 months)

Dr. R. A. Braga, Research Associate
(Oct. 1, 1974 - Present; 58.9% ERDA, 12 months)

Dr. W. R. Western, Research Associate
(Nov. 1, 1976 - Present; full-time, 12 months)

Dr. G. M. Gowdy, Research Associate
(July 1 - Aug. 31, 1977; terminated August 31, 1977)
(Present address: On-Line Isotope Separator Project,
GSI, Darmstadt, West Germany)

Dr. D. A. McClure, Assistant Professor (Physics)
(supported by School of Physics; terminated June 30, 1977)

Graduate Students:

Mr. Chris Papanicolopoulos (Physics). Continuing PhD thesis research.
(1/2 time ERDA since June 1, 1975)

Mr. Marvin A. Grimm (Physics). Continuing PhD thesis research.
(on ORAU fellowship in residence at UNISOR, Oak Ridge)

Mr. Bruce Gnade (Chemistry). Beginning PhD thesis research.
(on teaching assistantship Sept. 1, 1976 - Aug. 31, 1977;
1/2 time ERDA since September 1, 1977)

High School Summer Participant:

Mr. David Brown, summer, 1977, from Baldwin High School, Millidgeville, Georgia. (Supported by a NSF summer program for high school students.)

8.0 LIST OF PUBLICATIONS, PRESENTATIONS AT MEETINGS, LECTURE TOURS AND
OUTSIDE SEMINARS 1977

- 1) "The Decay of Mass Separated $^{201m, g}Po$," W. R. Western, J. L. Wood, R. A. Braga, and R. W. Fink, Bull. Am. Phys. Soc. 22 (1977) Rochester, N. Y. October, 1977 [ORO-3346-213]
- 2) "Production of 13-15 MeV Neutrons in A Reactor with an Enriched 6Li D Irradiation Capsule," C. Papanicolopoulos and R. W. Fink, Nuclear Instr. & Meth. (submitted, 1977) [ORO-3346-211]
- 3) "Decay of Mass Separated $^{195, 197}Tl$," R. A. Braga, G. M. Gowdy, J. L. Wood, and R. W. Fink, Presented at the Nuclear Chemistry Symposium, Am. Chem. Soc., Chicago, Ill., Aug. 29, 1977 [ORO-3346-210]
- 4) "Decay Scheme Studies and Nuclear Systematics far from the Line of Beta Stability," (Invited Paper), J. L. Wood, Presented at the Nuclear Chemistry Symposium, Am. Chem. Soc., Chicago, Ill, Aug. 28, 1977 [ORO-3346-209]
- 5) "Nuclear Systematics far from the Line of Beta Stability: Their Use, Strengths, and Weaknesses," J. L. Wood, Bull. Am. Phys. Soc. 22, (1977) Rochester, N. Y., October, 1977 [ORO-3346-212]
- 6) "The Systematics of the $h_{9/2}$ State in the Region $Z \leq 82$," J. L. Wood, Bull. Am. Phys. Soc. 22, 643 (1977) Washington, D. C., April, 1977 [ORO-3346-203]
- 7) "Shape Coexistence in ^{186}Hg and the Decay of ^{186}Tl ," J. D. Cole, K. R. Baker, A. Xenoulis, J. L. Wood, R. W. Fink, and other UNISOR coauthors, Nuclear Phys. (1977) [ORO-3346-208]
- 8) BOOK CHAPTER: "Thermal Neutron Reaction Cross Sections," R. W. Fink, in Handbook of Spectroscopy, 2nd Ed, Vol. 3, edited by R. W. Robinson, (CRC Publishing Co., Cleveland, Ohio, 1978); pp. [ORO-3346-206]
- 9) BOOK CHAPTER: "Tables of Experimental Values of X-ray Fluorescence and Coster-Kronig Yields for the K-, L-, and M-Shells," R. W. Fink and P. V. Rao, in Handbook of Spectroscopy, 2nd Ed, Vol. 3, edited by R. W. Robinson (CRC Publishing Company, Cleveland, 1978); pp. [ORO-3346-202]
- 10) "New Isomers of $^{185, 187}Tl$ and the Departure of the $h_{9/2}$ Intruder State," A. G. Schmidt, G. M. Gowdy, J. L. Wood, and R. W. Fink, with other UNISOR coauthors, Phys. Lett. 66B, 133-135 (1977)
- 11) "Decay of Mass Separated ^{185}Tl , ^{185}Hg , and the Structure of ^{185}Au ," A. Visvanathan, M. A. Grimm, J. L. Wood, R. W. Fink, and other UNISOR coauthors, Bull. Am. Phys. Soc. 22, 615 (1977) Washington, D. C. April, 1977 [ORO-3346-205]
- 12) "Decay of Mass Separated ^{200}Po ," C. R. Bingham, R. A. Braga, W. R. Western, and R. W. Fink, Bull. Am. Phys. Soc. 22, 546 (1977) Washington, D. C. April, 1977
- 13) "The UNISOR ISOL Data Acquisition System," H. K. Carter, R. A. Braga, and other UNISOR coauthors, Nuclear Instr. & Meth. 139, 349-353 (1976).

- 14) "Recent Work at UNISOR on Neutron Deficient Au, Hg, and Tl Nuclei in the Mass Region $184 \leq A \leq 197$," J. L. Wood, G. M. Gowdy, R. W. Fink, D. A. McClure, M. S. Rapaport, R. A. Braga, with other UNISOR coauthors, Proc. 3rd Int. Conf. on Nuclei far from Stability, Corsica, France, May, 1976, CERN Report 76-13 (1977); pp. 364-366 [ORO-3346-190]

Publications appearing after the 1976 Annual Report Date

- 15) "High and Low Spin Levels in ^{197}Tl ," L. L. Collins, M. S. Rapaport, J. L. Wood, R. W. Fink, and other UNISOR coauthors, Bull. Am. Phys. Soc. 21, 976 (1976) East Lansing, Michigan, October, 1976
- 16) "Evidence for Quadrupole Pairing Deformation," J. L. Wood and R. W. Fink, Bull. Am. Phys. Soc. 21, 1001 (1976) East Lansing, Michigan, October, 1976.
- 17) "The L_2 - L_3 Coster-Kronig Transition Probability at $Z = 96$," D. W. Nix and R. W. Fink, Z. Physik A278, 239-240 (1976)
- 18) "The K-Shell Conversion Coefficient of the 135.5 keV M_4 Transition in ^{193m}Pt Decay," A. I. Saleh, R. A. Braga, and R. W. Fink, Z. Physik A279, 27 - 29 (1976)
- 19) "Decay of Mass Separated ^{190}Tl and ^{190}Hg ," C. R. Bingham, J. L. Wood, G. M. Gowdy, R. W. Fink, and other UNISOR coauthors, Phys. Rev. C14, 1586-1600 (1976)
- 20) "An External Beam Technique for Proton-Induced X-ray Emission Analysis," A. Katsanos, A. Xenoulis, A. Hadjiantoniou, and R. W. Fink, Nuclear Instr. & Meth. 137, 119 -124 (1976)
- 21) PhD Thesis: "Decay Scheme Studies of Neutron Deficient Odd Mass Thallium Isotopes and the Systematics of the Odd Mass Mercury Levels," Gregory Michael Gowdy (Georgia Tech, December, 1976)

Lectures and Seminars Presented Off Campus

R. W. Fink, National Academy of Science, lecture tour to Poland and West Germany (May, 1977)

Lectures presented:

- a) "UNISOR—University On-Line Isotope Separator for the Study of Nuclei far from Stability with Heavy Ion Beams" [a general presentation with color slides, technical physics, and overview of the research program]

Presented at:

Institute of Experimental Physics, Univ. of Warsaw, Poland,
May 17, 1977

Institute of Nuclear Physics, Crakow, Poland, May 11, 1977

Institute of Nuclear Physics, Technische Hochschule, Darmstadt,
West Germany, May 26, 1977

- b) "Recent Nuclear Models and Systematics of Nuclear Structure in the Transition Region of Odd Mass Pt to Bi Nuclei" [a phenomenological overview of UNISOR experimental results and their analysis according to new models of nuclear structure]

Presented at: Institute of Theoretical Physics, Univ. of Warsaw,
Poland, May 19, 1977

- c) "Continuing Studies of Nuclei far from Stability with the UNISOR Facility" [research in progress and proposed new extensions; the 25 MV Folded Tandem Van de Graaff injector accelerator under construction; and newest developments in nuclear models and systematics]

Presented at: Cyclotron Institute, Univ. of Warsaw, Poland, May 20, 1977

- d) "PIXE—Proton-Induced X-ray Emission Analysis with an External Beam of Trace Elements in Biomedical (Cancer), Environmental, Geological, and Archeological Specimens"

Presented at:

Institute of Nuclear Techniques, School of Mining Technology,
Crakow, Poland, May 14, 1977

Physikalische-Technische Bundesanstalt, Braunschweig, West Germany
May 25, 1977

- e) "The Use of an Enriched ${}^6\text{LiD}$ Irradiation Capsule to produce 13-15 MeV Neutrons in a Reactor"

Presented at: Institute of Nuclear Research, Swierk, Poland, May 23, 1977

- f) "X-ray Fluorescence Yields and Coster-Kronig Transition Probabilities using Radioactive Sources"

Presented at: Cyclotron Institute, Univ. of Warsaw, Poland, May 21, 1977

R. W. Fink, (Invited Paper) "Proton-Induced X-ray Emission Multi-element Analysis in Biomedical, Environmental, Geological, and Archeological Specimens," Am. Nuclear Soc. Meeting, San Francisco, Nov. 27-Dec. 2, 1977.

J. L. Wood, "UNISOR Work and Nuclear Systematics: Evidence for Quadrupole Pairing,"
Presented at: UNISOR Information Meeting, Oak Ridge National Laboratory,
September 29, 1976

J. L. Wood, "The $h_{9/2}$ Intruder State, Quadrupole Pairing, and Possible Evidence
for Alpha-type Correlations,"

Presented at: State University of New York at Stony Brook, Dept. of
Physics, March 2, 1977