

**ANL-01/19**

ARGONNE NATIONAL LABORATORY  
9700 S. Cass Avenue  
Argonne, Illinois 60439-4801

**PHYSICS DIVISION ANNUAL REPORT**  
**2000**

Donald F. Geesaman  
Director

**September 2001**

Preceding Annual Reports

ANL-98/24 1997  
ANL-99/12 1998  
ANL-00/20 1999

Edited by Karen J. Thayer

## FOREWORD

This report summarizes the research performed in 2000 in the Physics Division of Argonne National Laboratory. The Division's programs include operation of ATLAS as a national user facility, nuclear structure and reaction research, nuclear theory and medium energy physics research, and accelerator research and development. As the Nuclear Science Advisory Committee and the nuclear science community create a new long range plan for the field in 2001, it is clear that the research of the Division is closely aligned with and continues to help define the national goals of our field.

The NSAC 2001 Long Range Plan recommends as the highest priority for major new construction the Rare Isotope Accelerator (RIA), a bold step forward for nuclear structure and nuclear astrophysics. The accelerator R&D in the Physics Division has made major contributions to almost all aspects of the RIA design concept and the community was convinced that this project is ready to move forward.

2000 saw the end of the first Gammasphere epoch at ATLAS. One hundred Gammasphere experiments were completed between January 1998 and March 2000, 60% of which used the Fragment Mass Analyzer to provide mass identification in the reaction. The experimental program at ATLAS then shifted to other important research avenues including proton radioactivity, mass measurements with the Canadian Penning Trap and measurements of high energy gamma-rays in nuclear reactions with the MSU/ORNL/Texas A&M BaF<sub>2</sub> array. ATLAS provided 5460 beam-research hours for user experiments and maintained an operational reliability of 95%. Radioactive beams accounted for 7% of the beam time. ATLAS also provided a crucial test of a key RIA concept, the ability to accelerate multiple charge states in a superconducting heavy-ion linac. This new capability was immediately used to increase the performance for a scheduled experiment.

The medium energy program continued to make strides in examining how the quark-gluon structure of matter impacts the structure of nuclei and extended the exquisite sensitivity of the Atom-Trap-Trace-Analysis technique to new species and applications.

All of this progress was built on advances in nuclear theory, which the Division pursues at the quark, hadron, and nuclear collective degrees of freedom levels.

These are just a few of the highlights in the Division's research program. The results reflect the talents and dedication of the Physics Division staff and the visitors, guests and students who bring so much to the research.

---

Donald Geesaman, Director, Physics Division



# TABLE OF CONTENTS

	<u>Page</u>
<b>I. HEAVY-ION NUCLEAR PHYSICS RESEARCH.....</b>	<b>1</b>
<b>A. REACTIONS OF ASTROPHYSICAL IMPORTANCE USING STABLE AND EXOTIC BEAMS .....</b>	<b>3</b>
a.1. The Influence of the First Excited $1/2^+$ State in $^{17}\text{F}$ on the $^{14}\text{O}(\alpha,p)^{17}\text{F}$ Reaction Rate.....	3
a.2. Spin Determination of Particle Unbound States in $^{18}\text{Ne}$ .....	5
a.3. Study of the Branching Ratio of the 4.033 MeV $J^\pi = 3/2^+$ State in $^{19}\text{Ne}$ .....	6
a.4. Large Angle Alpha Scattering on $^{44}\text{Ti}$ .....	7
a.5. Measurement of $^{44}\text{Ti}$ Half-Life.....	9
a.6. Measurement of $^{44}\text{Ti}$ Nucleosynthesis by $\gamma$ and Atom Counting.....	9
a.7. Study of Proton-Unbound States in Astrophysically-Interesting Nuclei.....	11
a.8. Reaction Rates of the $^{22}\text{Na}(p,\gamma)$ and $^{22}\text{Ne}(p,\gamma)$ Breakout Reactions.....	11
a.9. Excited States in $^{139}\text{Te}$ and the Properties of the r-Process Nuclei with $Z \sim 50$ and $N > 86$ .....	12
<b>B. STRUCTURE OF NUCLEI AT THE LIMITS OF PROTON INSTABILITY .....</b>	<b>15</b>
b.1. Alignment Delays in Even-Even $N = Z$ Nuclei.....	15
b.2. Structure of $N = Z$ Odd-Odd Nuclei, Including ( $N = Z = 35$ $^{70}\text{Br}$ ).....	16
b.3. New Results in Proton Radioactivity.....	17
b.4. Identification of Excited Structures in Proton Unbound Nuclei $^{173,175,177}\text{Au}$ : Shape Co-Existence and Intruder Bands.....	18
b.5. Measurements of g-Factors of Excited States in Zr and Mo Nuclei Using $\gamma$ Rays from Secondary Fission Fragments .....	24
b.6. Few Particle Excitations of the $N = 83$ Isotones $^{134}\text{Sb}$ and $^{135}\text{Te}$ .....	25
b.7. Coulomb Excitation of $^{124,126}\text{Xe}$ Studied with Segmented Germanium Detectors.....	26
<b>C. SPECTROSCOPY OF THE TRANS-LEAD NUCLEI.....</b>	<b>29</b>
c.1. Entry Distributions of $^{220}\text{Th}$ - The Measurement of Fission Barriers at High Angular Momentum.....	29
c.2. Study of $^{232}\text{Th}$ and Neighboring Nuclei with "Unsafe" Coulomb Excitation.....	31
c.3. Level Structures of the Pu Isotopes Studies by Coulomb Excitation.....	32
c.4. Proton Transfer Reactions on $^{237}\text{Np}$ , $^{241}\text{Am}$ and $^{248}\text{Cm}$ .....	33
c.5. Level Structure of $^{249}\text{Bk}$ from $\alpha$ Decay of $^{253}\text{Es}$ .....	35
c.6. Energy Levels in $^{251}\text{Cf}$ Populated in the $\alpha$ Decay of $^{255}\text{Fm}$ .....	35
c.7. Nuclear Structure and Fission Studies with $^{252}\text{Cf}$ .....	36
c.8. Spectroscopy of the Transfermium Nucleus $^{252}\text{No}$ .....	37
c.9. Structure, Fission Barrier and Limits of Stability of $^{253}\text{No}$ .....	37
c.10. Relativistic Mean-Field Calculations of the Structure of Very Heavy Nuclei .....	40

<b>D.</b>	<b>TESTS OF NUCLEAR STRUCTURE IN EXTREME CONDITIONS .....</b>	<b>41</b>
d.1.	First Identification of a $J = 10^+$ State in $^{24}\text{Mg}$ .....	42
d.2.	Search for Multi-Step Radiative Capture Decay of $^{24}\text{Mg}$ Following the $^{12}\text{C} + ^{12}\text{C}$ Reaction.....	44
d.3.	Lifetime of the Superdeformed Band in the $N = Z$ Nucleus $^{36}\text{Ar}$ .....	46
d.4.	Band Structure of $^{68}\text{Ge}$ .....	47
d.5.	Stability of Oblate Shapes in the $N = Z + 1$ Nucleus $^{69}\text{Se}$ .....	47
d.6.	Superdeformation in $^{91}\text{Tc}$ .....	49
d.7.	$^{98}\text{Tc}$ , BIC and the Lifetime of the 21.8-keV Level.....	50
d.8.	High-Spin States in $Z \approx 59$ , $A \approx 130$ Nuclei.....	51
d.9.	Experimental Determination of the Excitation Energy, Spin and Parity of the Yrast Superdeformed Band in $^{152}\text{Dy}$ from the 4010-keV One-step Linking Transition .....	52
d.10.	First Evidence for Triaxial Superdeformation in $^{168}\text{Hf}$ .....	55
d.11.	First Observation of Excited Structure in Neutron-Deficient $^{179}\text{Hg}$ : Evidence for Multiple Shape Coexistence .....	55
d.12.	First Observation of Rotational Band in Neutron-Rich $^{180}\text{Lu}$ .....	57
d.13.	High-Seniority Intrinsic and Collective Structures in $^{174}\text{Hf}$ and $^{175}\text{Hf}$ .....	58
d.14.	Inelastic Excitation of New High-Spin Yrast Isomer in $^{180}\text{Ta}$ .....	59
d.15.	Interplay Between Octupole and Quasiparticle Excitations in $^{178}\text{Hg}$ and $^{180}\text{Hg}$ .....	60
d.16.	Shape Competition and Octupole Correlations in Light Even-Even Pt Nuclei.....	62
d.17.	Spectroscopy of Neutron-Deficient Odd-Mass $^{173,175}\text{Pt}$ Nuclei.....	63
d.18.	Excited Rotational Bands in the Superdeformed Well of $^{194}\text{Hg}$ .....	64
d.19.	BaF <sub>2</sub> Collaboration to Measure High Energy $\gamma$ Rays.....	65
d.20.	The GDR Structure in Sn Nuclei from Highly Exclusive Studies.....	67
d.21.	GDR Studies in Exclusively Tagged Er Isotopes.....	68
d.22.	Structure of Hot Dy Nuclei as a Function of Spin and Excitation Energy.....	69
d.23.	Hot GDR in $^{118}\text{Sn}$ .....	69
d.24.	Hot GDR and Dissipation in $^{224}\text{Th}$ .....	70
d.25.	High-Energy Photons from Very Symmetric Reactions: The Giant Dipole Resonance in Highly Rotating Cold Nuclei.....	71
d.26.	A New Phenomenon in Heavy-Ion Fusion Reactions at Very Low Cross Sections .....	72
d.27.	Yield Calculations for an Advanced Rare Isotope Accelerator Facility.....	75
<b>E.</b>	<b>RELATIVISTIC HEAVY ION COLLISIONS .....</b>	<b>79</b>
e.1.	The PHOBOS Experiment at RHIC .....	79
e.2.	Studies of Au + Au Collisions at 6, 8, 10.8 GeV/Nucleon at the AGS.....	89

	<u>Page</u>
<b>F. FUNDAMENTAL INTERACTIONS AND OTHER TOPICS.....</b>	<b>95</b>
f.1. Specific Heat and Phase Transition in Confined Ionic Systems.....	95
f.2. Comparison of Classical Configurations in Two-Dimensional Confinement with Those of the Quantum-Mechanical System of Quantum Dots.....	98
f.3. A Proposed Method for Measuring the Electric Dipole Moment of the Neutron by a Large Improvement of the Shull Method.....	99
f.4. The Quest for a Detection Method of Natural <sup>39</sup> Ar.....	99
f.5. Ultra-Sensitive Detection of <sup>244</sup> Pu by Accelerator Mass Spectrometry .....	101
<b>G. EQUIPMENT DEVELOPMENT .....</b>	<b>103</b>
g.1. Gammasphere Operations.....	103
g.2. Move of Gammasphere to LBNL .....	105
g.3. Response of Gammasphere to High Energy Gamma Rays.....	106
g.4. Development of HpGeDSSD Planar Detectors for the Gamma-Ray Box (GARBO).....	106
g.5. Delay-Line Shaping Amplifiers for a Double-Sided Silicon Strip Detector.....	107
g.6. PICA Data-Acquisition Development .....	108
g.7. Nuclear Target Development.....	108
g.8. Progress at the Canadian Penning Trap Mass Spectrometer.....	110
<b>H. ASSISTANCE TO OUTSIDE USERS OF ATLAS .....</b>	<b>113</b>
a. Experiments Involving Outside Users.....	113
b. Outside Users of ATLAS During the Period 10/1/1999 - 9/30/2000.....	119
<b>II. OPERATION AND DEVELOPMENT OF ATLAS .....</b>	<b>123</b>
<b>A. OPERATION OF THE ACCELERATOR .....</b>	<b>124</b>
Operations Summary.....	124
<b>B. DEVELOPMENTS RELATED TO ATLAS .....</b>	<b>125</b>
b.1. Status of the 14-GHz Ion Source (ECR-II) .....	126
b.2. Upgrade of the ATLAS ECR-I Ion Source.....	127
b.3. Vibration Damper .....	129
b.4. PII Injection Bunching System.....	130
b.5. ATLAS Control System.....	131
b.6. ATLAS Cryogenic System .....	131
b.7. New Solenoid for the In-Target Production of Radioactive Beams at ATLAS....	131
b.8. New Charge-State Acceleration of Uranium in ATLAS.....	132
b.9. Superconducting Cavity Development for ATLAS .....	134

<b>III. R &amp; D RELATED TO A FUTURE ADVANCED EXOTIC BEAM FACILITY</b> .....	135
<b>A. SUPERCONDUCTING LINAC TECHNOLOGY</b> .....	137
a.1. Drift-Tube Cavity Development .....	137
a.2. Surface Preparation Lab Upgrades.....	138
a.3. Drift-Tube Cryomodule Design.....	139
a.4. Coupler and Tuner Development.....	140
a.5. RIA Cryogenics .....	140
<b>B. RIA BEAM DYNAMICS</b> .....	141
b.1. Multiple-Charge Dynamics .....	141
b.2. Demonstration of Simultaneous Acceleration of Multiply-Charged Ions Through a Superconducting Linac .....	142
b.3. Two-Charge State Driver Injector.....	142
b.4. Layout of a Magnetic Optical System for Transport and Matching of Multiple-Charge-State Heavy-Ion Beams.....	143
b.5. Preliminary Design of the Driver Linac Switchyard.....	144
b.6. Low-Charge-State Injector Beam Dynamics .....	146
b.7. Singly-Charged Heavy-Ion Beam Studies on a 12-MHz RFQ .....	148
<b>C. RARE ISOTOPE BEAM PRODUCTION AND SEPARATION TECHNOLOGY</b> .....	150
c.1. Development of a Large Accelerated Gas-Cell System for the Collection of Fast Recoiling Radioactive Ions .....	150
c.2. Liquid Lithium Films for Ion Stripping.....	152
c.3. Liquid Lithium for High Power Density Fragmentation Targets .....	153
c.4. Optimization of ISOL Targets Based on Monte Carlo Simulations of Ion Release Curves .....	154
c.5. Design Layout of an Isobar Separator for Purifying Beams of Rare Isotopes ....	157
c.6. Validation of Two-Step Target Simulations.....	158
<b>D. RARE ISOTOPE BEAM DIAGNOSTICS</b> .....	160
d.1. Design and Test of a Beam Profile Monitoring Device for Low-Intensity Radioactive Beams .....	160
<b>IV. MEDIUM-ENERGY NUCLEAR PHYSICS RESEARCH</b> .....	163
<b>A. SUBNUCLEONIC EFFECTS IN NUCLEI</b> .....	165
a.1. New Measurement of ( $G_E/G_M$ ) For the Proton.....	165
a.2. The Energy Dependence of Nucleon Propagation in Nuclei as measured in the (e,e'p) Reaction .....	167

	<u>Page</u>	
a.3.	Measurements of $R = \sigma_L/\sigma_T$ in the Nucleon Resoance Region.....	168
a.4.	Measurement of Proton Polarization in Neutral Pion Photoproduction .....	168
a.5.	Two-Body Photodisintegration of the Deuteron Up to 5.5 GeV .....	169
a.6.	Measurement of Proton Polarization in Deuteron Photodisintegration .....	171
a.7.	Angular Distribution of the $\gamma d \rightarrow pn$ Reaction.....	172
a.8.	High Energy Pion Photoproduction from the Proton and Deuteron .....	173
a.9.	A Study of Longitudinal Charged-Pion Electroproduction in D, $^3\text{He}$ , and $^4\text{He}$ ...	173
a.10.	Pion Electroproduction from $\text{H}_2$ and $\text{D}_2$ at $W = 1.95$ GeV .....	175
a.11.	Measurement of the Structure Function of the Pion.....	175
a.12.	Electroproducton of Kaons and Light Hypernuclei.....	176
a.13.	Measurements of Inclusive Cross Section in the Nucleon Resonance Region....	178
a.14.	Measurements of the Nuclear Dependence of $R = \sigma_L/\sigma_T$ at Low $Q^2$ .....	179
a.15.	A Precise Measurement of the Nuclear Dependence of Structure Functions in Light Nuclei.....	180
a.16.	HERMES, Measurements of Spin-Structure Functions and Semi-Inclusive Asymmetries for the Proton and Neutron at HERA.....	181
a.17.	A Dual Radiator Ring Imaging Cerenkov Counter for HERMES.....	188
a.18.	An Exploration of the Antiquark Sea of the Proton Using Drell-Yan Scattering.	190
a.19.	Nuclear Dependence of Lepton Pair Production: Parton Energy Loss, Shadowing, and $J/\Psi$ and $\Psi'$ Suppression .....	191
a.20.	Production of $\Upsilon$ and $J/\Psi$ from 800-GeV Protons Incident on $\text{D}_2$ and $\text{H}_2$ Targets.....	192
a.21.	Polarization Measurements of $\Upsilon$ and $\Psi$ Production in Proton-Nucleus Collisions.....	193
a.22.	Lepton Pair Production with 120-GeV Protons to Extend the Measurement of $\bar{d}/\bar{u}$ in the Nucleon .....	194
 <b>B. ATOM TRAP TRACE ANALYSIS.....</b>		 <b>196</b>
b.1.	Building a Practical ATTA System for $^{81}\text{Kr}$ Dating .....	196
b.2.	Atom Trap Trace Analysis of $^{41}\text{Ca}$ .....	197
b.3.	Measuring the Charge Radius of $^6\text{He}$ .....	198
b.4.	Feasibility Study for Atomic Parity Violation Measurements in the Hydrogen Isotopes .....	199
 <b>V. THEORETICAL PHYSICS.....</b>		 <b>201</b>
 <b>A. NUCLEAR DYNAMICS WITH SUBNUCLEONIC DEGREES OF FREEDOM.....</b>		 <b>202</b>
a.1.	$K \rightarrow \pi\pi$ and a Light Scalar Meson.....	202
a.2.	Selected Nucleon Form Factors and a Composite Scalar Diquark.....	203
a.3.	Temperature-Dependence of Pseudoscalar and Scalar Correlations.....	203
a.4.	Temperature, Chemical Potential and the $\rho$ Meson .....	203
a.5.	Dyson-Schwinger Equations: Denisty, Temperature and Continuum Strong QCD .....	204

	<u>Page</u>	
a.6.	Valence-Quark Distributions in the Pion.....	204
a.7.	Contemporary Applications of Dyson-Schwinger Equations.....	205
a.8.	Diquarks and Density .....	205
a.9.	Pair Creation and Plasma Oscillations.....	206
a.10.	Neutron Electric Dipole Moment: Constituent-Dressing and Compositeness.....	206
a.11.	Plasma Production and Thermalization in a Strong Field.....	207
a.12.	Axial-Vector Diquarks in the Baryon.....	207
a.13.	$J/\psi$ Suppression as a Signal of Quark Gluon Plasma Formation.....	207
a.14.	Valence-Quark Distributions in the Nucleon.....	208
a.15.	Dynamical Study of the $N^*$ Excitation in $N(e,e'\pi)$ Reactions.....	208
a.16.	Nucleon Resonances in $\omega$ Production.....	210
a.17.	Coupled-Channel Approach for $K^+\Lambda$ Photoproduction.....	212
a.18.	Meson-Exchange $\pi N$ Models in Three-Dimensional Bethe-Salpeter Formulations.....	212
a.19.	$\phi$ -N Bound State .....	212
a.20.	Compressed Nuclei with $\Delta$ 's and Hyperons .....	213
a.21.	Medium Effects on $J/\psi$ Propagation.....	214
a.22.	Dynamical Test of Constituent Quark Models with $\pi N$ Reactions.....	214
a.23.	Quantum Monte Carlo Calculations of Pion Scattering from Light Nuclei .....	215
a.24.	Two-Nucleon Correlations in Meson Scattering from $^{16}\text{O}$ .....	216
a.25.	Relativistic Quantum Dynamics of Many-Body Systems .....	216
a.26.	Null-Plane Dynamics of Elastic Electron Deuteron Scattering.....	216
<b>B.</b>	<b>NUCLEAR FORCES AND NUCLEAR SYSTEMS.....</b>	<b>217</b>
b.1.	Quantum Monte Carlo Calculations of Light p-shell Nuclei .....	218
b.2.	Studies of Three-Nucleon Interactions in Nuclear Systems .....	210
b.3.	Radiative Capture Reactions for Astrophysical Applications.....	220
b.4.	Microscopic Calculation of $A = 6-8$ Weak Decays.....	222
b.5.	Coupled Cluster Expansion Approach to Calculating Ground State Properties of Closed Shell Nuclei in the p-Shell .....	222
b.6.	Coupled Cluster Calculation for Single Particle States and the Magnetic Form Factor .....	223
b.7.	Meson Exchange Effects in p-Shell Nuclei.....	223
b.8.	Comparison of M1 and EL Properties for Light 1p-shell Nuclei .....	223
b.9.	Studies of Hypernuclei.....	225
b.10.	Neutron-Proton Density Differences in Nuclei.....	225
<b>C.</b>	<b>NUCLEAR STRUCTURE AND HEAVY-ION REACTIONS.....</b>	<b>226</b>
c.1.	Coupled-Channels Treatment of Deformed Proton Emitters.....	227
c.2.	Vibrational Interpretation of Spherical and Near-Spherical Proton Emitters.....	228
c.3.	Accuracy of Eikonal Model of Fragmentation Reactions .....	228
c.4.	Analyses of $^8\text{B}$ Coulomb Dissociation Experiments.....	230
c.5.	Giant Resonances in Exotic Nuclei .....	231
c.6.	Many-Body Wave Functions.....	231
c.7.	Very Extended Shapes in Nuclei.....	232
c.8.	Single-Particle States in the Heaviest Elements .....	233
c.9.	Studies of Nuclear Energy Surfaces.....	234
c.10.	Neutron-Proton Pairing.....	236

	<u>Page</u>
<b>D. ATOMIC THEORY AND FUNDAMENTAL QUANTUM MECHANICS</b> .....	236
d.1. Interactions of Photons with Matter .....	237
d.2. Interactions of Charged Particles with Matter .....	237
d.3. Superluminal Behavior in Wave Propagation.....	238
d.4. Space Searches with a Quantum Robot.....	238
d.5. The Representation of Numbers in Quantum Mechanics .....	239
<b>E. OTHER ACTIVITIES</b> .....	239
e.1. Perspectives in Continuum Strong QCD .....	239
e.2. 13 <sup>th</sup> Annual Midwest Nuclear Theory Get-Together .....	240
 <b>OTHER EDUCATIONAL ACTIVITIES IN THE PHYSICS DIVISION</b> .....	 241
a. Enhancement of Minority Involvement in DOE Nuclear Physics Programs.....	241
b. Nuclear Physics Award for Faculty in Undergraduate Institutions .....	241
c. Scientific Support of SciTech Museum Exhibits and Outreach Programs .....	242
 Staff List.....	 243
Publications .....	255

