TUNL XXXIX

PROGRESS REPORT

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TRIANGLE UNIVERSITIES NUCLEAR LABORATORY

DUKE UNIVERSITY
NORTH CAROLINA STATE UNIVERSITY
UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL

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Introduction

The Triangle Universities Nuclear Laboratory (TUNL) – a collaboration of Duke University, North Carolina State University, and the University of North Carolina at Chapel Hill – has had a very productive year. The following reports cover parts of the last year and first year of two three-year grants between the U.S. Department of Energy and the three collaborating universities.

During the current grant period TUNL physicists have achieved major successes:

- **Double-beta decay:**
  
  With a 1 kg isotopically enriched (98.4%) $^{100}$Mo sample we have accumulated, for the first time, a practically background free $\gamma$-ray coincidence spectrum resulting from the double-beta decay to the first excited $0^+$ state in $^{100}$Ru. After 440 days of counting our result is $T_{1/2} = (5.8^{+1.5}_{-1.0}) \times 10^{20}$ years.

- **Gamma-ray physics at the DFELL:**
  
  The first measurement using the 100% polarized $\gamma$-ray beam confirms the expected M1 contribution in the $^2$H($\gamma,n)^{1}$H reaction at $E_\gamma = 3.6$ MeV. Preliminary results of a new measurement at $E_\gamma = 3.2$ MeV indicate an M1 strength which is considerably larger than theory.

- **Parity nonconservation in the nuclear interaction:**
  
  Analysis of TRIPLE collaboration parity violation data confirms the existence of local fluctuations in the weak spreading width.

- **KamLAND:**
  
  About 250 Kamiokande 20” photomultiplier tubes (PMTs) have been refurbished, tested and attached to modified frames. The support structure for these frames at the bottom (55 PMTs), the sides (120 PMTS) and the top (50 PMTs) of the KamLAND Outer Detector has been designed.

- **Nucleon-deuteron analyzing power puzzle:**
  
  Our new low-energy $n$-$d A_y(\theta)$ data support our earlier conjecture that the energy dependence of the $n$-$d$ and $p$-$d A_y(\theta)$ puzzles is very different, making this puzzle even more elusive.
• **$^{76}$Ge detector:**
  We have acquired about 4 kg of 80% enriched $^{76}$Ge for the construction of a segmented $^{76}$Ge detector for double-beta decay studies.

• **Underground physics:**
  TUNL has been chosen as the first institution to conduct fundamental physics research at the DOE Waste Isolation Pilot Plant (WIPP) underground facility near Carlsbad, NM. WIPP is providing the entire infrastructure needed to install the present TUNL/ITEP double-beta decay apparatus underground.

• **Chaos in the nucleus:**
  Established complete spectroscopy for $^{30}$P. The large effect of the small isospin symmetry breaking on the spacing distribution that was first observed in $^{26}$Al is confirmed in $^{30}$P. The deviation of the reduced transition matrix elements from the Porter-Thomas distribution is also observed in $^{30}$P.

• **Three-nucleon forces:**
  Measurements of cross sections and analyzing powers in proton-deuteron elastic scattering taken at several energies have been compared to state-of-the-art calculations to reveal that excellent agreement with all observables, with the notable exception of vector analyzing powers, is only possible when a three-nucleon force is included in the interaction potential.

• **Three-nucleon dynamics:**
  Preliminary analysis of our recent cross-section measurements at 16.0 MeV confirms the space-star anomaly in neutron-deuteron ($nd$) breakup observed at low energies. Our data are about 20% higher than rigorous $nd$ calculations.

• **Sub-Coulomb $\alpha$-transfer reactions:**
  We are studying the $^{12}$C($\alpha$,γ)$^{16}$O reaction indirectly by measuring ($^6$Li, d) and ($^7$Li, t) on $^{12}$C at sub-Coulomb energies. New measurements of $^{12}$C($^7$Li,t)$^{16}$O(1γ) and particle-gamma correlations provide tests of this new technique.

• **Neutron magnetic form factor measurements:**
  The first determination of the neutron magnetic form factor ($G_{Mn}$) by inclusive quasi-elastic scattering of longitudinally polarized electrons from a polarized $^3$He target was performed at Jefferson Lab at $Q^2$ values of 0.1 and 0.2 (GeV/c)$^2$. These new results are important for interpretation of parity-violation experiments in terms of the strange content of the proton.

• **Gerasimov-Drell-Hearn Sum Rule in $^2$H and $^3$He near threshold:**
  Our polarized $p + d$ and $d + p$ capture data have shown that the GDH sum rule
integral for $^3$He in the threshold region ($E_p < 80$ keV) is about two times larger than state-of-the-art three-body calculations, which include MEC effects.

- **Holifield Radioactive Ion Beam Facility:**
  We have measured $^{17}$P$(p,\alpha)$ and $^{18}$F$(p,p)$ reactions at ORNL as part of our program in explosive nucleosynthesis. This information is relevant to the evolution of nova light curves.

- **A possible new resonance in $^{14}$N$(p,\gamma)^{15}$O:**
  We have obtained data which show evidence for a possible new resonance in the $^{14}$N$(p,\gamma)^{15}$O reaction near $E_p = 130$ keV. An effort to confirm this is underway.

- **Laboratory for Experimental Nuclear Astrophysics:**
  The 1 MV JN accelerator is now running under computer control. Attention is now focused on the 200 kV accelerator.

- **Polarized ion source:**
  A new high-efficiency ionizer for spin-polarized atoms is closer to reality with our recent experimental proof that a 5 mm diameter, 2 mA H$^+$ plasma jet can be created and propagated 40 cm along the axis of a 1000 Gauss solenoidal magnetic field.

- **Gas-jet target:**
  The gas-jet target has operated successfully and produced excellent, background-free spectra when a jet of $^4$He was bombarded by 4 MeV protons. The width of the jet was measured to be about 1 mm over a wide range of densities. These densities were directly proportional to the input-flow rate over the range of flow-rates studied.

- **Cs sputter source:**
  We have installed a Cs sputter source which produces intense beams of heavy ions for injection into the FN tandem. The source expands the capabilities of the laboratory, allowing experiments such as sub-Coulomb alpha-transfer studies to be performed in house.

- **Nuclear data project:**
  We have completed and distributed a review of $A = 7$ nuclei and are preparing to publish “Energy Levels of Light Nuclei $A = 5-7$.” Preliminary reviews of $A = 8$ and $A = 9$ are underway. Web documents and services have been expanded to take advantage of links into the NSR database at the NNDC and links to major online journals. ENSDF files have been updated for $A = 11-13$.

- **Evaluation of thermonuclear proton capture reaction rates:**
  We have used our previous studies of proton capture reactions, including polarization
measurements, to re-evaluate several reaction rates. Differences as large as 50% are found, when compared to the most recent compilation.

- **Nucleosynthesis calculations:**
  We completed the compilation and evaluation of 55 proton-induced thermonuclear reaction rates involving target nuclei in the $A = 20-40$ mass range. Our new results will substantially improve stellar model predictions of nucleosynthesis in novae, supernovae and red giant stars.

TUNL seeks to be on several of the nuclear physics research frontiers identified in the 1996 NSAC Long Range Plan. The TUNL research program focuses on the following areas:

- Precision test of parity-invariance violation in resonance neutron scattering at LANSCE/LANL.
- Parity violation measurements using charged-particle resonances in $A = 20-40$ targets at TUNL.
- Chaotic behavior in the nuclei $^{26}$Al and $^{30}$P from studies of eigenvalue fluctuations in nuclear level schemes.
- Search for anomalies in the level density (pairing phase transition) in $1f-2p$ shell nuclei.
- Nuclear astrophysics, using the refurbished Enge split-pole spectrometer, the Low-Energy Beam Facility, a new 200 keV accelerator for high-intensity unpolarized beams, and the KN accelerator (all at TUNL); facilities at HRIBF, Argonne, and Notre Dame; and the HIGS facility presently under construction at Duke’s FELL. Emphasis is placed on the following topics:
  - abundance anomalies in globular clusters
  - explosive nucleosynthesis in novae
  - evolution of massive stars
  - origin of galactic radioactivity
  - the solar neutrino problem
- Study of double-beta decay to excited $0^+$ states.
- Time dependence of the weak-interaction coupling constant.
- Neutrino studies at KamLAND.
Introduction

- Few-body nuclear systems, with specific experiments to address:
  - radiative-capture reactions on hydrogen isotopes to investigate non-nucleonic degrees of freedom
  - the role of three-nucleon forces in the 3N and 4N continuum using hadronic and electromagnetic probes
  - the strength of the tensor force in the NN interaction
  - search for “scaling” in the three-nucleon continuum
  - the $A_y(\theta)$ and $iT_{11}$ puzzles in 3N scattering
  - the quark structure of nucleons in experiments at JLAB

- Nuclear Data evaluation for $A = 3-20$ for which TUNL is now the international center. Extensive services are provided through our WWW site and are constantly being improved.

Developments in technology and instrumentation are vital to our research and training program. We continued our innovative work in:

- polarized beam development
- polarized target development
- detector development
- polarimeters for charged particles and $\gamma$ rays
- improving high-resolution beams for the KN and FN accelerators
- development of a Laboratory for Experimental Nuclear Astrophysics for radiative-capture studies of astrophysical interest.

Although a final decision has not been made, we expect funding of the TUNL/DFELL proposal to DOE to develop an intense beam of polarized $\gamma$ rays. Duke University will contribute $650,000 to the project. This High-Intensity Gamma-ray Source (HIGS) will utilize the facilities of the Duke Free-Electron Laser Laboratory (DFELL). The DFELL currently includes a 250 MeV LINAC injector, a 1.1 GeV electron storage ring, and the OK-4 undulator. It is possible to tune the electron beam in a manner which allows the FEL photons produced by one electron bunch to backscatter from a second electron bunch, all within the ring. This leads to an intense beam of almost 100% polarized $\gamma$ rays whose
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energy can be readily tuned from about 2 MeV to greater than 200 MeV. Furthermore, beam energy spreads of less than 1% can be obtained by purely geometrical collimation. In order to achieve the full range of energies, it will be necessary to upgrade the energy of the injected beam to 1.2 GeV and to make modifications in the electron beam optics in the FEL storage ring. Funds for upgrading the injected beam energy to 1.2 GeV, which will allow us to produce γ rays up to about 220 MeV, will constitute the major part of the proposal.


The Nuclear Data Evaluation project for nuclei \( A = 3–20 \), which was moved to TUNL in 1990, continues not only to benefit our local research, but is also providing an important service to the international nuclear physics community.

TUNL conducted its first year as an NSF supported Research Experience for Undergraduates (REU) program site. Twelve students participated in this 10 week summer program.

The TUNL seminar program continues with characteristic vigor (25 invited speakers), supplemented by 16 in-house lectures on TUNL instrumentation and safety procedures and 6 lectures on Advances in Physics. A related program, the Triangle Nuclear Theory colloquia, is also beneficial to TUNL faculty and students.

The talents and enthusiasm of the 17 faculty members, 13 research staff and post-doctoral associates, and more than 30 graduate students from the three Triangle universities are responsible for the successes of our research program. We also benefit from collaborations with Tennessee Technological University, North Georgia College and State University, North Carolina A&T State University, Shaw University, Penn State Altoona, State University of New York-Geneseo, Idaho State University, Gettysburg College, China Institute of Atomic Energy and Tsinghua University (Beijing), Jagellonian University (Cracow), and Istituto Nazionale di Fisica Nucleare (Pisa).

The TUNL Advisory Committee - Drs. David Balamuth (University of Pennsylvania), Baha Balantekin (University of Wisconsin), James Friar (Los Alamos National Laboratory), Gerald Garvey (Los Alamos National Laboratory), and Steven Vigdor (Indiana University) - continues to provide valuable advice on the research program.

The research summaries presented in this progress report are preliminary. They should not be referenced in other publications. If you wish to know the current status of a project, please contact the person whose name is underlined in the author list or a senior author.
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<td>Raichle, B.</td>
<td>Morehead State University</td>
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<td>Shriner, J. F.</td>
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<tr>
<td>Spraker, M.</td>
<td>North Georgia College and State University</td>
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<tr>
<td>Stephenson, S.</td>
<td>Gettysburg College</td>
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<tr>
<td>Weisel, G.</td>
<td>Penn State Altoona</td>
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Research Staff

Bardayan, D. (Research Associate)  UNC
Churchwell, S. (Research Associate) Duke
Dummer, A. (Research Associate)  UNC
Kalbach Walker, C. (Senior Research Scientist)  Duke
Markoff, D. (Research Associate)  NCSU
Nakamura, K. (Research Associate)  Duke
Nesaraja, C. (Research Associate) Duke
Rohm, R. (Research Scientist)  NCSU
Roper, C.¹ (Research Associate) Duke
Stephan, A.² (Research Associate) UNC
Waman, K.³ (Research Associate)  Tennessee Tech. Univ.
Westerfeldt, C. (Research Scientist, Radiation Safety Manager) Duke
Wulf, E.⁴ (Research Associate) Duke

Technical, Secretarial and Nuclear Data Support Staff for TUNL

Carlin, B. P. Electronics Technician
Carter, E. P. Accelerator Supervisor
Cheves, C. M.⁵ Project Coordinator
Dunham, J. D. Accelerator Technician
Edwards, S. E.⁶ Computer Maintenance Supervisor
Godwin, J. L. Project Coordinator
Mulkay, P. H. Electronics Technician
O’Quinn, R. M. Accelerator Technician
Pulis, T. E. Staff Assistant
Scripa, M.⁷ Research Secretary
Sheu, G. Research Secretary
West, B. Research Secretary
Williamson, S. Electronics Technician Trainee

¹ left 9/99
² left 10/99
³ left 11/99
⁴ left 1/00
⁵ left 10/99
⁶ left 12/99
⁷ left 8/00
Graduate Students

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<tr>
<th>Name</th>
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<tr>
<td>Agyaanhuvsan, U.</td>
<td>NCSU</td>
<td>Macri, R.</td>
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<td>Beal, W.</td>
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<td>Milanovich, G.</td>
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<td>Leonard, D.</td>
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<td>Wood, M.</td>
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<td>Lokitz, S.</td>
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Visiting Scientists

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<tr>
<th>Name</th>
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<tbody>
<tr>
<td>Mohammad Al-Ohali</td>
<td>7/00–8/00</td>
<td>King Fahd Univ. of Petroleum and Minerals, Saudi Arabia</td>
</tr>
<tr>
<td>Frank Avignone</td>
<td>3/00</td>
<td>University of South Carolina</td>
</tr>
<tr>
<td>Alexander Barabash</td>
<td>2/00, 6/00</td>
<td>ITEP, Moscow, Russia</td>
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<tr>
<td>Timothy Black</td>
<td>5/00–6/00</td>
<td>UNC - Wilmington</td>
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<tr>
<td>Kurt Fletcher</td>
<td>1/00</td>
<td>SUNY-Geneseo</td>
</tr>
<tr>
<td>Chris Frankie</td>
<td>11/99, 6/00</td>
<td>Los Alamos National Laboratory</td>
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<tr>
<td>Kara Keeter</td>
<td>5/00–8/00</td>
<td>Idaho State University</td>
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<tr>
<td>Alejandro Kievsky</td>
<td>9/99–5/00,</td>
<td>INFN, Pisa, Italy</td>
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<tr>
<td>Xiuqin Lu</td>
<td>6/00–present</td>
<td>China Institute of Atomic Energy</td>
</tr>
<tr>
<td>Cal Moss</td>
<td>11/99, 6/00</td>
<td>Los Alamos National Laboratory</td>
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<tr>
<td>Mauricio Pato</td>
<td>7/00</td>
<td>University of Sao Paulo, Brazil</td>
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<tr>
<td>Ron Pedroni</td>
<td>9/99–present</td>
<td>North Carolina A&amp;T State University</td>
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<tr>
<td>Filipe Santos</td>
<td>9/99</td>
<td>University of Lisbon</td>
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<td>Edouard Sharapov</td>
<td>6/99–11/99, 7/00–present</td>
<td>JINR, Dubna, Russia</td>
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<tr>
<td>Tatsushi Shima</td>
<td>8/00–9/00</td>
<td>RCNP, Osaka, Japan</td>
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<tr>
<td>Ivo Slaus</td>
<td>4/00</td>
<td>Rudjer Boskovic, Zagreb, Croatia</td>
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1graduated between Sept. 99 and Aug. 00
Gary Weisel 7/00 Penn State Altoona
Scott Wilburn 7/00 Los Alamos National Laboratory
Henryk Witała 9/99, 8/00 Jagellonian University, Cracow, Poland

Temporary Graduate Student Personnel

Carron, S. Duke
Lush, J. Duke
Simmons, W.N. Duke

Undergraduates

Clarkson, B. Univ. of Virgin Islands
Culberson, W. Furman Univ.
Enaya, H. NC State Univ.
Horton, P. Duke Univ.
Khader, Y. UNC - Pembroke
Oram, J. Idaho State Univ.
Perry, J. NC A&T
Reisner, W. Reed College
Sabourović, A. Idaho State Univ./NC State Univ.
Santos, P. UNC - Pembroke
Schwentker, A. Duke Univ.
Tanner, P. NC State Univ.
White, A. NC A&T