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PROGRESS REPORT

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Triangle Universities Nuclear Laboratory

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Contents

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 second and third year of a three-year grant 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 γ-ray coincidence spectrum resulting from the double-beta decay to the first excited 0^+ state in ^{100}Ru. After 5.5 months of counting our result is $T_{1/2} = (5.2 \pm 1.5) \times 10^{20}$ years.

- **Neutron-neutron scattering length** a_{nn}:
  The first simultaneous and accurate determination of the ^{1}S$_0$ neutron-neutron and neutron-proton scattering lengths were made at TUNL. The results of these measurements resolve the long standing anomaly between a_{nn} obtained from π^--d and n-d data.

- **Parity nonconservation in the nuclear interaction**:
  The observation of parity-violation effects of both signs at higher energies in ^{232}Th establishes that the previously found anomalous sign correlation is localized in energy. This result is consistent with local doorway-state theory predictions.

- **Meson-exchange currents**:
  Polarized p-d and d-p radiative capture data enabled us to evaluate the Gerasimov-Drell-Hearn Sum-Rule integral for ^{3}He in the γ-^{3}He threshold region. Our value differs by a factor of 10 from rigorous $3N$ calculations using the "nucleon-only" approximation, but only by a factor of two when MEC effects are included.

- **The tensor force in the nucleon-nucleon interaction**:
  By scattering longitudinally polarized neutrons from a longitudinally polarized proton

target we determined the nucleon-nucleon tensor force from the analysis of our $\Delta = \Delta\sigma_L - \Delta\sigma_T$ total cross-section difference measurements between 5 and 20 MeV. Our data suggest that the tensor force is larger than predicted by meson-exchange based nucleon-nucleon potential models, questioning the strong ρ-coupling used in these models.

- **Astrophysical S factors**:
  New T_{20} measurements suggest that the ^{2}H(d,γ)^{4}He reaction is not predominantly s-wave capture at energies near 100 keV, but is dominated by p-wave capture. This finding will effect the extrapolated S-factor result. The negative slope of the S factor for ^{7}Li(p,γ)^{8}Be is now understood and results in an increase of S at $E = 0$ from 0.3 to 0.5 keV-b.

- **Chaos in the nucleus**:
  Our determination of the effect of symmetry breaking on the distribution of electromagnetic transition strength in ^{26}Al, which shows strong departure from the Porter-Thomas distribution, has been qualitatively confirmed by three new theoretical calculations.

- **Proton-deuteron scattering at low energies**:
  We have completed scattering measurements of protons from deuterons and vice versa at center-of-mass energies of 432 and 667 keV. These experiments show that the discrepancy between rigorous 3N calculations and data for $A_y(\theta)$ and $iT_{11}(\theta)$ approaches the stunning value of 40% at the lowest energy, while the tensor analyzing powers are rather well described.

- **Three-nucleon forces**:
  The comparison of our result obtained for the neutron-proton scattering length from the neutron-deuteron breakup reaction with the value measured in free neutron-proton scattering clearly shows that three-nucleon force effects are less important in the three-nucleon final-state interaction configuration than previously thought. However, for space-star configurations our new measurements indicate large three-nucleon force effects.

- **Sub-Coulomb α-transfer reactions**:
  We have studied the ^{12}C(α,γ)^{16}O reaction indirectly by measuring the ^{12}C(^{6}Li,d)^{16}O and ^{12}C(^{7}Li,t)^{16}O reactions at sub-Coulomb energies. These measurements have provided accurate information on the subthreshold 2^+ state, which places strong constraints on the low-energy E2 S factor.

- **High-accuracy measurements of the proton electric form factor at JLAB**:
  The new determinations of the ratio of the electric and magnetic form factors of the

proton made at six Q^2 points between 0.5 and 3.5 $(GeV/c)^2$ show a definite deviation from the dipole form for the electric form factor. This result may have important consequences in understanding the nucleon-spin problem.

- **Globular clusters**:
  We have determined the total width of the $E_x = 223$ keV resonance in $^{24}Mg(p,\gamma)^{25}Al$ and have determined new reaction rates for $^{22}Ne(p,\gamma)^{23}Na$ and $^{23}Na(p,\gamma)^{24}Mg$. Our results strongly suggest that low mass stars in globular clusters evolve through stages that are poorly understood in terms of mixing and hydrodynamics.

- **Holifield Radioactive Ion Beam Facility**:
  Using the first radioactive beam delivered at ORNL, we have measured the energy and width of the astrophysically significant 3^+ state in ^{18}Ne via the $^{1}H(^{17}F,p)^{17}F$ reaction.

- **Gamma-ray physics at the DFELL**:
  The FEL generated 100% polarized γ-ray beam was used to measure the analyzing power of the $^{2}H(\gamma,n)^{1}H$ reaction near the photodisintegration threshold region. Our data should determine the M1/E1 ratio in this energy range for the first time.

- **Polarized target**:
  The TUNL dynamically polarized proton target was converted into a polarized deuteron target and the first $\vec{n}$-$\vec{d}$ total cross-section difference data $\Delta\sigma_L$ were obtained.

- **Laboratory for Experimental Nuclear Astrophysics**:
  We have almost completed the construction of the Laboratory for Experimental Nuclear Astrophysics (LENA) at TUNL. This state-of-the-art facility is designed to produce intense beams of protons with energies up to 1 MeV for measurements of astrophysically interesting reactions.

- **Polarized ion source**:
  Toward our goal of developing more intense polarized beams, tests of a new intense and highly collimated hydrogen-ion plasma jet from an ECR source show our scheme to be a promising new basis for creating a more efficient ionizer of spin-polarized deuterium atoms by charge exchange at ~ 1 eV.

- **Charged-particle parity violation studies**:
  A 2π α-particle detector system with 64 segments consisting of 4 large silicon strip detectors is being used for charged-particle parity-violation studies in the $^{31}P(p,\alpha)^{28}Si$ reaction.

- **Gas-jet target**:
  We have completed the installation of a windowless high-density recirculating gas-jet

target that we acquired from the University of Erlangen. First ^{14}N(p,p)^{14}N data were taken.

- **Nuclear data project**:
  We completed the review "Energy Levels of Light Nuclei A = 20." Preliminary versions for A = 5 and A = 6 have been completed and distributed. The review of A = 7 is underway. We also increased our World Wide Web (WWW) service. Updated and/or revised ENSDF files have been prepared for A = 2–10 and A = 16–20.

- **The ^{14}N(p,γ)^{15}O reaction**:
  We have measured the lifetime of the 6.793 MeV state in ^{15}O, which is a subthreshold resonance in the ^{14}N(p,γ)^{15}O reaction. We also have performed exploratory measurements of ^{14}N(p,γ)^{15}O at E_p = 140 keV using unpolarized and polarized proton beams.

- **Nucleosynthesis calculations**:
  For the purpose of obtaining more reliable predictions for nucleosynthesis calculations, we have developed a theoretical framework to estimate random errors of resonant thermonuclear reaction rates.

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 Caltech; 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.
- Neutrino studies at KamLAND.
- 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 γ 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.

We submitted a proposal to DOE to develop an intense beam of polarized γ rays. 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 γ rays whose 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.

In the development of polarized targets we successfully converted the dynamically polarized proton target at TUNL into a vector polarized deuteron target.

With respect to innovative detector and target developments, we have put in operation a unique detector system to study double-beta decay transitions to excited states. We have also installed a recirculating gas-jet target.

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.

The TUNL seminar program continues with characteristic vigor (23 invited speakers), supplemented by 19 in-house lectures on TUNL instrumentation and safety procedures and 3 lectures on Advances in Physics. A related program, the Triangle Nuclear Theory seminars, 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, North Carolina Central University, 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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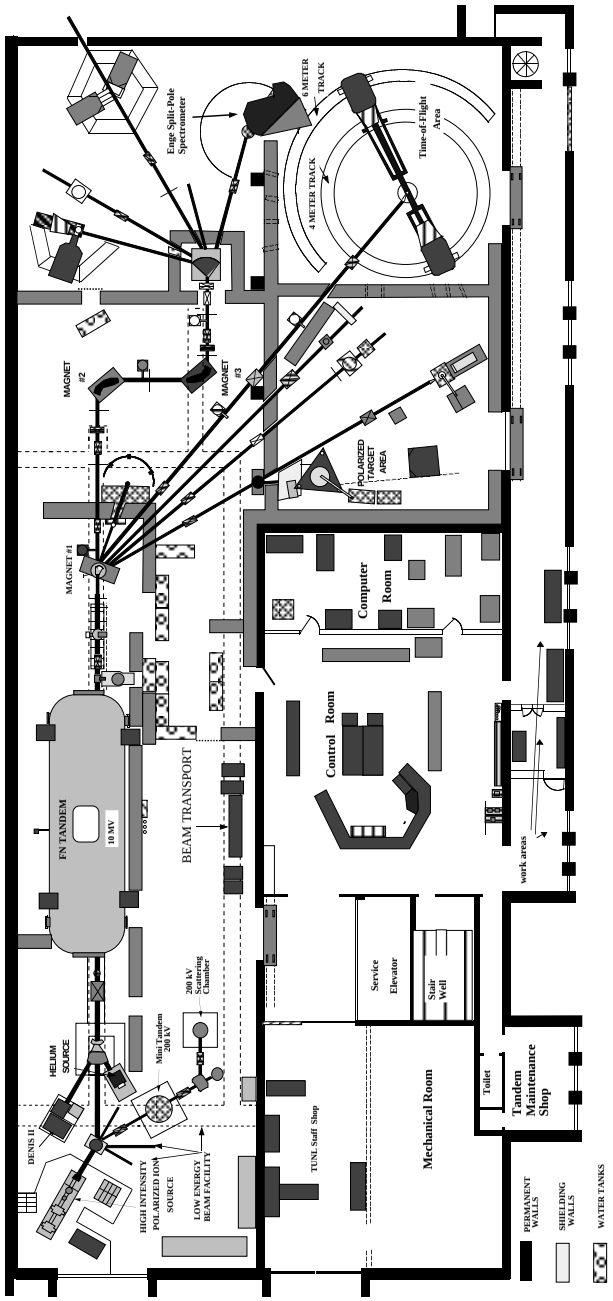

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[1] left 4/99
[2] left 12/98
[3] left 1/99
[4] left 3/99

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Alejandro Kievsky	9/98–12/98, 3/99	INFN, Pisa, Italy
Dennis McNabb	5/99	Los Alamos National Laboratory
Cal Moss	5/99	Los Alamos National Laboratory

[1] graduated between Sept. 98 and Aug. 99

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Scott Wilburn	12/98, 7/99	Los Alamos National Laboratory

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