The Time Projection Chamber is an innovative approach to carry out precision fission measurements at the Los Alamos Neutron Science Center. This $4\pi$ detector system will provide unprecedented data about the fission process.
Approvals

Mike Heffner, Principal Investigator Date 08/31/08

Nolan Hertel, Principal Investigator Date 08/31/08

Tony Hill, Principal Investigator Date 08/31/08

John Baker, Principal Investigator Date 08/31/08
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Submitted Papers, Reports and Summaries

NERI Monthly Reports for January-October, edited by T. Hill, submitted to NERI Program Office

NERI 2nd Quarter Report, edited by T. Hill, submitted to NERI Program Office
NERI 3rd Quarter Report, edited by T. Hill, submitted to NERI Program Office
NERI 4th Quarter Report, edited by T. Hill, submitted to NERI Program Office

A Time Projection Chamber for Precision $^{239}$Pu(n,f) Cross Section Measurement, M. Heffner (LLNL), AIP, CP1005, pp 182-185.


**Presentations**

A Time Projection Chamber for Precision $^{239}$Pu(n,f) Cross Section Measurement, M. Heffner (LLNL), contributed talk presented at the Fission and Properties of Neutron-Rich Nuclei Conference, Sanibel, FL, November 2007

The Fission TPC Project, M. Heffner (LLNL), contributed talk presented at the TPC Workshop, Michigan State University, Michigan, December 2007

The Fission TPC Project, M. Heffner (LLNL), contributed talk presented at the Tigress Workshop, Livermore, CA February 2008

New Fission Cross Section Measurements Using a Time Projection Chamber, M. Sadler (ACU), contributed talk presented at the Texas Section of the American Physical Society, Corpus Christi, TX, March 2008


Nuclear Data Requirements for GNEP, T. Hill (LANL), contributed talk presented at the 2008 GNEP Semi-Annual Review Meeting, April 2008

The Global Nuclear Energy Partnership and the Need for Precision Nuclear Data, T. Hill (LANL), contributed talk presented at the 2008 Annual Meeting of the American Nuclear Society, Anaheim, CA, June 2008

A Time Projection Chamber for Precision $^{239}$Pu(n,f) Cross Section Measurement, M. Heffner (LLNL), contributed talk presented at the 2008 Annual Meeting of the American Nuclear Society, Anaheim, CA, June 2008

Developing a software and computing framework for the NIFFTE TPC, J.L. Klay (CalPoly), contributed talk presented at the 2008 Annual Meeting of the American Nuclear Society, Anaheim, CA, June 2008

Towards a Precision $^{235}$U(n,f)/H(n,n)H Measurement, T. Massey (OU), contributed talk presented at the 2008 Annual Meeting of the American Nuclear Society, Anaheim, CA, June 2008

Future Upgrades to the TPC, T. Hill (LANL), contributed talk presented at the 2008 Annual Meeting of the American Nuclear Society, Anaheim, CA, June 2008
The Fission TPC Project, M. Heffner (LLNL), contributed talk presented at the CAARI 2008, Ft. Worth, TX, June 2008

The Fission TPC Project, M. Heffner (LLNL), contributed talk presented at the 4th Nuclear Data Workshop, Aldermaston, England, September 2008


Basic Nuclear Physics Research Needs for Nuclear Energy, T. Hill (LANL), invited talk at the APS Division of Nuclear Physics Meeting, Oakland, CA, October 2008

The Fission TPC Project, T. Hill (LANL), contributed talk at the APS Division of Nuclear Physics Meeting, Oakland, CA, October 2008

### Student Participation

<table>
<thead>
<tr>
<th>Institution</th>
<th>Undergraduate</th>
<th>Graduate</th>
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<tr>
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<td>Cal Poly San Luis Obispo</td>
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<tr>
<td>Georgia Institute of Technology</td>
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<td>Oregon State University</td>
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</table>

### Student Presentations

NERI-C TPC Project Plan and Progress, E. Burgett (GIT), contributed talk presented at the 2008 Annual Meeting of the American Nuclear Society, Anaheim, CA, June 2008

Preliminary Collimator Design for a Time Projection Chamber Installation at LANSCE, E. Burgett (GIT), contributed talk presented at the 2008 Annual Meeting of the American Nuclear Society, Anaheim, CA, June 2008

Design of a Gas Delivery System for the NIFFTE TPC, L. Snyder (Colorado School of Mines), contributed talk at the Seventh Exotic Beams Summer School at the Argonne National Lab, Chicago IL, Aug 8th 2008

GEANT4 Simulation of the NIFFTE TPC, T. Thornton (ACU), contributed talk at the 2008 Texas/Four Corners APS Sections, El Paso, TX, October 2008
Introduction to NIFFTE and its Data Acquisition System, A. White (ACU), contributed talk at the 2008 Texas/Four Corners APS Sections, El Paso, TX, October 2008 – received award

Track Reconstruction for the NIFFTE TPC, S. Sharma (ACU), contributed talk at the 2008 Texas/Four Corners APS Sections, El Paso, TX, October 2008 – received award

Student Posters

Design of a Gas Delivery System for the NIFFTE TPC, presented by L. Snyder (Colorado School of Mines) at the Seventh Exotic Beams Summer School at the Argonne National Lab, Chicago IL, Aug 8th 2008

Fission Time Projection Chamber Status Report, presented by L. Snyder (Colorado School of Mines) at the 2008 GNEP Annual Review Meeting, Idaho Falls, ID, October 2008 – received award

Fission Time Projection Chamber Project, presented by E. Burgett (Georgia Institute of Technology) at the 2008 GNEP Annual Review Meeting, Idaho Falls, ID, October 2008 – received award

TPC tracking software for NIFFTE: the Neutron Induced Fission Fragment Tracking Experiment, presented by R. Kudo (CalPoly) at the 2008 APS-DNP Meeting, Oakland, CA, 2008 – received award

NIFFTE Overview and Goals, presented by S. Stewart (ACU) at the 2008 APS-DNP Meeting, Oakland, CA, October 2008 – received award

GEANT4 Simulation of the NIFFTE TPC, presented by T. Thornton (ACU), at the 2008 APS-DNP Meeting, Oakland, CA, October 2008 – received award

Track Reconstruction for the NIFFTE TPC, presented by S. Sharma (ACU), at the 2008 APS-DNP Meeting, Oakland, CA, October 2008 – received award
# Acronyms and Symbols

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACU</td>
<td>Abilene Christian University</td>
</tr>
<tr>
<td>AFC</td>
<td>Advanced Fuel Cycle</td>
</tr>
<tr>
<td>AFM</td>
<td>Atomic Force Microscopy</td>
</tr>
<tr>
<td>Am</td>
<td>Americium</td>
</tr>
<tr>
<td>ANL</td>
<td>Argonne National Laboratory</td>
</tr>
<tr>
<td>ANS</td>
<td>American Nuclear Society</td>
</tr>
<tr>
<td>ASME</td>
<td>American Society of Mechanical Engineers</td>
</tr>
<tr>
<td>Atm</td>
<td>Atmosphere (pressure unit)</td>
</tr>
<tr>
<td>Ba</td>
<td>Barium</td>
</tr>
<tr>
<td>Be</td>
<td>Beryllium</td>
</tr>
<tr>
<td>Bi</td>
<td>Bismuth</td>
</tr>
<tr>
<td>BNL</td>
<td>Brookhaven National Laboratory</td>
</tr>
<tr>
<td>CalPoly</td>
<td>California Polytechnic State University, San Luis Obispo</td>
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<tr>
<td>Ce</td>
<td>Cerium</td>
</tr>
<tr>
<td>Cm</td>
<td>Curium</td>
</tr>
<tr>
<td>CS</td>
<td>cross section</td>
</tr>
<tr>
<td>Cs</td>
<td>Cesium</td>
</tr>
<tr>
<td>CSM</td>
<td>Colorado School of Mines</td>
</tr>
<tr>
<td>Cu</td>
<td>Copper</td>
</tr>
<tr>
<td>CVD</td>
<td>Chemical Vapor Deposition</td>
</tr>
<tr>
<td>DANCE</td>
<td>Detector for Advanced Neutron Capture Experiment</td>
</tr>
<tr>
<td>DAQ</td>
<td>Data Acquisition System</td>
</tr>
<tr>
<td>DOE</td>
<td>Department of Energy</td>
</tr>
<tr>
<td>dpa</td>
<td>Displacements per Atom</td>
</tr>
<tr>
<td>EIS</td>
<td>Environmental Impact Statement</td>
</tr>
<tr>
<td>ENDF</td>
<td>Evaluated Nuclear Data File - Evaluations that can be used in MCNPX for more accurate predictions of fission, criticality, transport, and radiation damage</td>
</tr>
<tr>
<td>ES&amp;H</td>
<td>Environmental, Safety, and Health</td>
</tr>
<tr>
<td>Eu</td>
<td>Europium</td>
</tr>
<tr>
<td>Fe</td>
<td>Iron</td>
</tr>
<tr>
<td>FPGA</td>
<td>Field-programmable gate array</td>
</tr>
<tr>
<td>FWHM</td>
<td>Full Width Half Maximum</td>
</tr>
<tr>
<td>GEANT4</td>
<td>Geometry And Tracking monte carlo program from CERN</td>
</tr>
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<td>GIT</td>
<td>Georgia Institute of Technology</td>
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<tr>
<td>GNASH</td>
<td>Nuclear Reaction Code</td>
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<tr>
<td>GNEP</td>
<td>Global Nuclear Energy Partnership</td>
</tr>
<tr>
<td>H</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>He</td>
<td>Helium</td>
</tr>
<tr>
<td>HEU</td>
<td>Highly enriched uranium</td>
</tr>
<tr>
<td>Hf</td>
<td>Hafnium</td>
</tr>
<tr>
<td>Hg</td>
<td>Mercury</td>
</tr>
<tr>
<td>IAC</td>
<td>Idaho Accelerator Center</td>
</tr>
<tr>
<td>IAEA</td>
<td>International Atomic Energy Association (Vienna, Austria)</td>
</tr>
<tr>
<td>IFR</td>
<td>Integral Fast Reactor</td>
</tr>
<tr>
<td>INL</td>
<td>Idaho National Laboratory</td>
</tr>
<tr>
<td>ISTC</td>
<td>International Science and Technology Centre (Moscow)</td>
</tr>
<tr>
<td>ITU</td>
<td>Institute for Transuranium Elements (Karlsruhe, Germany)</td>
</tr>
<tr>
<td>JAERI</td>
<td>Japan Atomic Energy Research Institute</td>
</tr>
<tr>
<td>JLAB</td>
<td>Jefferson Laboratory (VA)</td>
</tr>
<tr>
<td>K</td>
<td>Potassium</td>
</tr>
<tr>
<td>keV</td>
<td>Kiloelectron Volt</td>
</tr>
<tr>
<td>Kr</td>
<td>Krypton</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>LA150n</td>
<td>Los Alamos generated nuclear data library, extending up to 150 MeV</td>
</tr>
<tr>
<td>LAHET</td>
<td>Los Alamos High-Energy Transport</td>
</tr>
<tr>
<td>LANL</td>
<td>Los Alamos National Laboratory</td>
</tr>
<tr>
<td>LANSCE</td>
<td>Los Alamos Neutron Science Center</td>
</tr>
<tr>
<td>LLFP</td>
<td>Long Lived Fission Products</td>
</tr>
<tr>
<td>LLNL</td>
<td>Lawrence Livermore National Laboratory</td>
</tr>
<tr>
<td>MA</td>
<td>Minor actinide</td>
</tr>
<tr>
<td>mb</td>
<td>Millibarn</td>
</tr>
<tr>
<td>mCi</td>
<td>Millicurie</td>
</tr>
<tr>
<td>mips</td>
<td>Minimum ionizing particles</td>
</tr>
<tr>
<td>MCNP</td>
<td>Los Alamos High-Energy Transport (LAHET) and Monte Carlo N-Particle Codes</td>
</tr>
<tr>
<td>MCNPX</td>
<td>Merged code—Los Alamos High-Energy Transport (LAHET) and Monte Carlo N-Particle Codes (MCNP)</td>
</tr>
<tr>
<td>mL</td>
<td>Milliliter</td>
</tr>
<tr>
<td>Mo</td>
<td>Molybdenum</td>
</tr>
<tr>
<td>MOX</td>
<td>Mixed-oxide fuel</td>
</tr>
<tr>
<td>mR</td>
<td>Millirad (a measure of radiation)</td>
</tr>
<tr>
<td>N</td>
<td>Nickel or nitride</td>
</tr>
<tr>
<td>Np</td>
<td>Neptunium</td>
</tr>
<tr>
<td>NEA</td>
<td>Nuclear Energy Agency (Paris)</td>
</tr>
<tr>
<td>NEPA</td>
<td>National Environmental Protection Agency</td>
</tr>
<tr>
<td>NERAC</td>
<td>Nuclear Energy Research Advisory Committee</td>
</tr>
<tr>
<td>NERI</td>
<td>Nuclear Energy Research Initiative</td>
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<tr>
<td>NIFFTE</td>
<td>Neutron Induced Fission Fragment Tracking Experiment (TPC Collaboration name)</td>
</tr>
<tr>
<td>O</td>
<td>Oxygen or Oxide</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>Operations and Maintenance</td>
</tr>
<tr>
<td>ORNL</td>
<td>Oak Ridge National Laboratory</td>
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<tr>
<td>OSU</td>
<td>Oregon State University</td>
</tr>
<tr>
<td>OU</td>
<td>The Ohio University</td>
</tr>
<tr>
<td>PACS</td>
<td>Personnel Access Control System</td>
</tr>
<tr>
<td>Pb</td>
<td>Lead</td>
</tr>
<tr>
<td>Pd</td>
<td>Paladium</td>
</tr>
<tr>
<td>PNNL</td>
<td>Pacific Northwest National Laboratory</td>
</tr>
<tr>
<td>Pu</td>
<td>Plutonium</td>
</tr>
<tr>
<td>PUREX</td>
<td>Plutonium-Uranium Extraction</td>
</tr>
<tr>
<td>QA</td>
<td>Quality Assurance</td>
</tr>
<tr>
<td>R</td>
<td>Rad (a measure of radiation)</td>
</tr>
<tr>
<td>rms</td>
<td>root mean square</td>
</tr>
<tr>
<td>ROOT</td>
<td>an object oriented data analysis framework from CERN</td>
</tr>
<tr>
<td>RSICC</td>
<td>Radiation Safety Information Computational Center</td>
</tr>
<tr>
<td>Ru</td>
<td>Ruthenium</td>
</tr>
<tr>
<td>SEM</td>
<td>Scanning Electron Microscopy</td>
</tr>
<tr>
<td>SNF</td>
<td>Spent Nuclear Fuel</td>
</tr>
<tr>
<td>SNL</td>
<td>Sandia National Laboratory</td>
</tr>
<tr>
<td>SRS</td>
<td>Savannah River Site</td>
</tr>
<tr>
<td>STP</td>
<td>Standard Temperature and Pressure</td>
</tr>
<tr>
<td>Ta</td>
<td>Tantalum</td>
</tr>
<tr>
<td>Tc</td>
<td>Technitium</td>
</tr>
<tr>
<td>TEM</td>
<td>Transmission Electron Microscopy</td>
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<tr>
<td>TJNAF</td>
<td>Thomas Jefferson National Accelerator Facility</td>
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<tr>
<td>TPC</td>
<td>Time Projection Chamber</td>
</tr>
<tr>
<td>TRL</td>
<td>Technical Readiness Level</td>
</tr>
<tr>
<td>TRU</td>
<td>Transuranics (americium, curium, neptunium, and plutonium)</td>
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<tr>
<td>TRUEX</td>
<td>Aqueous solvent extraction process for TRU recovery</td>
</tr>
<tr>
<td>U</td>
<td>Uranium</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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</tr>
<tr>
<td>UREX</td>
<td>Uranium Extraction (an aqueous partitioning process)</td>
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<tr>
<td>V</td>
<td>Vanadium</td>
</tr>
<tr>
<td>W</td>
<td>Tungsten</td>
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<tr>
<td>WBS</td>
<td>Work Breakdown Structure</td>
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<td>WNR</td>
<td>Weapons Neutron Research (facility at LANSCE)</td>
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<tr>
<td>Xe</td>
<td>Xenon</td>
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<tr>
<td>Y</td>
<td>Yttrium</td>
</tr>
<tr>
<td>Zr</td>
<td>Zirconium</td>
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Time Projection Chamber Project

Introduction

Reactor core calculations are dependent on nuclear physics for cross sections and kinematics. Design codes interface the nuclear data through nuclear data libraries, which are a culmination of experimental results and nuclear theory and modeling. Uncertainties in the data contained in those libraries propagate into uncertainties in reactor performance parameters, such as: criticality, peak power, temperature reactivity, transmutation potential, radiotoxicity and decay heat in a repository. The impact of nuclear data uncertainties has been studied in detail for transmutation systems and sensitivity codes have subsequently been developed that provide nuclear data accuracy requirements based on adopted target accuracies on crucial design parameters. The sensitivity calculations have been performed for a number of candidate systems. These sensitivity studies provide specific requirements for uncertainties on many fission cross sections, many of which are beyond the reach of current experimental tools. The sensitivity codes are proving to be very useful for identifying the highest impact measurements for the GNEP program and the TPC measurement program will help provide those data. The result of these new precision measurements will be a reduction in the reactor core performance margins, thus reducing the construction and operating costs of the new reactor fleet. The new class of precision fission measurements will not be easy. The proposed method is to employ a Time Projection Chamber and perform fission measurements relative the H(n,n)H elastic scattering. The TPC technology has been in use in high-energy physics for over two decades - it is well developed and well understood. However, it will have to be optimized for this task which includes miniaturization, design for hydrogen gas, and large dynamic range electronics. The TPC is the perfect tool for minimizing most of the systematic errors associated with fission measurements. The idea is to engineer a TPC specifically for delivering fission cross section measurements with uncertainties below 1.0%.

The long term goal is to fill the TPC with hydrogen gas and measure fission cross sections relative to H(n,n)H elastic scattering, thus removing the uncertainties associated with using the U-235 fission cross section for normalization. In fact, we will provide the world's best differential measurement of the U-235 fission cross section and this will impact nearly all fission library data, since it has been used as a standard in much of the available fission experimental data.

The immediate objective of this effort is to implement a fission cross section measurement program with the goal of providing the most needed measurements with unprecedented precision using a time projection chamber. The first three years of this program will provide all the groundwork and infrastructure for a successful measurement campaign. Shortly following, we will provide precision fission ratio measurements for Pu-239/U-235 and U-238/U-235 along with a full design proposal to measure $^{235}\text{U}/(n,p)p$. The $^{235}\text{U}/(H(n,n))H$ measurement will provide the best single measurement of the U-235 fission cross section and will allow us to convert the initial, and any subsequent, ratio experiments to worlds best absolute measurements. After completion of the U-238 and Pu-239 ratio measurements, the experimenters will
move on to measurement of the minor actinide cross section, fission fragment
distribution and neutron yield measurements. This information will play a crucial role
in the long term GNEP reactor R&D campaign.

The reporting for this project is broken down into four categories:

- **TPC Hardware** activities include design, testing and operation of the
  complete time projection chamber, including gas system and electronics.
- **TPC Software** activities will provide the project with the required
  programming for the online data acquisition system, data reduction and
  analysis as well as simulation.
- **The Hydrogen Standard** will be used to minimize total cross section errors.
  The ability to accurately and precisely determine fission cross sections hinges
  on the H(n,n)H total cross section and angular distributions.
- **Facilities and Operations** will need to be identified and prepared for the
  construction, testing and operation of the TPC. This activity is spread
  amongst the collaborators, based on the work they are performing, such as
  target fabrication, computing, design, component testing, and operation.
- **Management** section describes the organizational work required for a project
  this size.

## TPC Hardware

### Scope

The components that make up the TPC proper are included in this section. This
includes the pressure vessel, field cage, pad-plane, gas amplifier, laser alignment
system, targets, electronics and the engineering required to integrate all of the parts
into a working system.

### Highlights

- TPC pressure vessel has been designed and a prototype constructed and
  successfully pressure tested.
- TPC field cage has been designed, fabricated and assembled. Initial load
  tests have been completed.
- A technique has been developed to create the micromegas gas amplification
  system in a reproducible manner. The micromegas system has achieved a
  gain factor of over 900, more than enough for the TPC application.
- The 32-channel preamplifier card has been designed with layout validated by
  manufacturer. Parts have been ordered and initial bench testing boards have
  been fabricated and delivered.
- The initial digital card design is complete. The Virtex-5 FPGA has been
  chosen and purchased. The initial design of the FPGA code is complete and
  documented.
• Resolved problem with Xilinx software that prevented the proper timing of the signals to the memory on the digital card. The FPGA timing constraints have been met for the high-speed components (memory and ADCs). A Full post route simulation model of FPGA has been completed. General optimization and improvement of the FPGA code for timing margin and robust operation was also competed.

• A laser alignment system has been purchased through Blue Ridge Optics that includes the necessary engineering support for final design and delivery.

• A new TPC layout design has been developed to insure proper cooling of the electronics.

• The EtherDAQ switch system has been assembled and tested for component compatibility. Initial packet sending and receiving tests have been successfully carried out.

• The slow control monitoring system is being assembled and tested. Initial communication with devices via ethernet has been confirmed.

• The gas handling system has been completely assembled and tested, meeting one of the stated project milestones for FY08. Modifications are underway to allow for remote computer control of the system.

• Target holder /cathode plane interfaces agreed upon, and initial cathode plane designed.

• Two $^{238}\text{U}$ targets were prepared using a newly developed “four source” technique. The variations in thickness of the targets are less than 1.5%. The preparation of these targets is now considered to be a routine matter involving only about ten days to prepare a target, and to measure its thickness and uniformity.

• The first $^{235}\text{U}$ target was prepared (99.9% pure $^{235}\text{U}$) and measured the associated alpha particle spectrum. The spectrum is dominated by the $^{234}\text{U}$ impurity (92% of the activity). One concludes that when the TPC is used to measure the tracks of the alpha particles emitted from the targets to determine target properties, the tracking will be with the $^{234}\text{U}$ impurities in the target rather than the primary nuclides.

### Time Projection Chamber [LLNL, LANL]

The TPC is the centerpiece of the experiment and consists of a number of parts that have to each be designed and integrated into a working whole. This section will describe the progress on each of the subsystems and tasks.

**Design**

The mounting of the electronics on the TPC has been designed and is shown in Figure 1 below. This design allows for significant airflow over the electronics for cooling, keeps the electronics away from the beam, and allows for access to the cards for servicing.
Figure 1: TPC with new electronics mounting scheme

The TPC will have baffles on either side and around the edge to direct the cooling air. Figure 2 shows a cross section of the TPC with the cooling baffles in place. The cooling air has a single point entry on the left and exist through the rectangular holes on the right. This design insures that the electronic heat load is carried away efficiently and minimizes the impact of the electronics on the vessel temperature.

Figure 2: Cross section of the TPC with cooling baffles in place.
**Micromegas and Pad Plane**

The pad plane is where the charge is read out. It will be built from a printed circuit board with about 3000 hexagon pads on each plane (see Figure 3). There are two planes for each TPC for a total of 6000 pads in one TPC. On top of the pad plane a gas gain structure will be placed. We are currently exploring the MicroMegas structure and have built a prototype that was manufactured by Streamline Circuits (see Figure 4). Performance testing of this prototype is ongoing.

![Figure 3: Prototype pad plane. The gold colored hexagons are 2mm across and are the charge collection electrodes. The mesh is held 100um over the surface by solder-mask pillars on the surface. A 300-400V potential is placed between the mesh and the pads.](image)

![Figure 4: A micorgraph of the setup shown in the previous picture. The standoffs are green circles in that hold the mesh above the pads.](image)
The MicroMegas design for this TPC has now archived a gain of 920. This is more than needed for the specified TPC performance and we have concluded this study for now. The test was performed with a $^{55}\text{Fe}$ source that emits a 5.9 keV x-ray. With careful triggering of 7 pads (1 center pad and its 6 neighbors), we were able to extract the 5.9 keV peak and also observed the 3 keV Argon escape peak. The MCA plot of the energy spectra are shown in Figure 5.

![Figure 5: Fe-55 MCA spectra with mesh voltage at 400V and 100V/cm drift field in P10 gas. The peak observed in the sum (black) of MCA channel one and channel two. Channel one is connected to a single pad surrounded by six pads all ganged into channel two. A reasonably large threshold in channel 1 guarantees that all the charge is collected in the sum of the 7 pads.](image)

The mesh used to construct the micromegas is only 3 μm thick and is therefore difficult to handle. We devised a method to stretch the mesh by heating a frame with the mesh attached, glue the mesh to the pad plane, let it cure and then cut the frame away. This worked rather well in the first attempt and we will refine this in the next quarter. A heating lamp was used to heat the frame and the operation was conducted in a class 100 clean bench to prevent contamination. Figure 6 shows the prototype in the clean bench.
Figure 6: Prototype pad plane in the clean bench.

Figure 7 shows a close up of the process. Notice how tight and smooth the mesh is in the rectangular frame. This is critical to the performance of the gas gain stage. The mesh is glued down and then cut away from the plastic frame.

Figure 7: Close up of the pad plane prototype and the mesh in the process of making a micromegas.
**Pressure Vessel**

The TPC is designed to operate with gas pressures up to 5 atm absolute with an inside diameter of 15 cm. This density of gas is sufficient to stop the alphas and fission fragments in the active volume of the TPC and provides for the measurement of the energy of the particle and the identification. Safety requirements specify that the operating pressure be only 80% of the relief device and that the vessel can withstand 4 times the pressure of the relief device. This works out to a pressure of 20 atm gauge pressure or about 294 psig. This is easily met because of the relatively small dimensions, and the final vessel only weighs a few pounds when made from aluminum (see Figure 8).

![Image of pressure vessel](image.png)

Figure 8: The TPC pressure vessel with support legs is shown here. The CAD design is on the left and the prototype vessel on the right.

**Field Cage**

The purpose of the field cage is to provide a uniform electric field throughout the active volume of the TPC. In this design that is the majority of the internal volume of the pressure vessel. This is accomplished with rings of copper on fr4 with step-down resistors that gradually reduce the voltage along the walls of the pressure vessel. Figure 9 shows the location inside the pressure vessel. It is the gold colored material inside the vessel. The parts have been designed and ordered for the prototype and construction of the first prototype will start soon.
Figure 9: Pressure vessel with the ends removed. The CAD design on the left shows the field cage (gold), cathode plane (yellow) and target (white). The prototype field cage is shown inside the prototype pressure vessel on the right without the target plane.

Figure 10 shows the service area outside of the field cage were the high-voltage is feed in and the step down resistors are located. A special resistor from Stackpole Electronics is being used that can withstand the high voltage gradients required in this application.

Figure 10: Service area outside of the field cage with the protective polyimide cover removed. On the left is the HV feed. The middle is the seam needed to form the field cage from the PCB. The right is the resistor ladder that steps down the voltage.

**Cathode Plane/ Target holder**

The prototype cathode plane was manufactured and delivered this quarter and installed into the field cage (Figure 11). Minor trimming was necessary to make a good fit due to the somewhat large tolerances in the PCB manufacturing. The cathode is bonded in place with a precision bead of epoxy placed with a medium sized syringe. Figure 12 shows a micrograph of the bond. Electrical contact is made with a graphite-loaded epoxy that is placed in a small bead on the reverse.
Figure 11: The cathode plane and target holder mounted in the cylindrical field cage.

Figure 12: Micrograph of the field cage/cathode plane bond near the field cage seam. The strip alignment at the seam is good, and the epoxy bond has filled the gap well without spreading beyond the first strip.

**Laser Alignment System**

The TPC will be designed to insure that a uniform drift field is maintained. The uniformity of the drift field has a direct impact on the quality of the tracking data. A laser system will be designed to allow us to monitor the quality of the field and to calibrate relative drifts between the many digitizing clocks. A company in Oak Ridge, Tennessee, has been selected to provide the optics for the system, which will consist of a bundle of quartz rods that will transmit the laser light from an Nd:YAG laser, quadrupled to 266 nm, into the TPC volume. The quartz rods will be of varying lengths and at the end of each rod a triple reflector that will split the beam into three
and deflect them into the TPC at 90 degree angles. An artist’s conception of the laser system is shown in Figure 13.

![Image of laser alignment system](image)

**Figure 13:** An artist’s rendering of the laser alignment system for the TPC. A bundle of different length quartz rods, each with a triple-splitter, 90 degree deflectors will direct beams into the TPC volume. The 266 nm beams will ionize the gas within the beams and the resulting data will track field distortions and relative timing drifts between 192 digitizer clocks.

**Data Acquisition System [LLNL, ACU]**

The TPC will have over 6000 pads, each of which need to be instrumented with a preamplifier, ADC and digital readout. The challenge of a large number of densely packed high-speed channels has been met in the past with custom ASIC chips. The technology of both ADC and FPGA has improved considerably over the last decade and it is now possible to use off-the-shelf components to accomplish the same task for considerably less development cost, less time to working prototypes, and considerably more flexibility in the final design.

**EtherDAQ Design**

The Virtex 5 chip from Xilinx has been selected for the design of the digital card and 400 have been purchased. The initial version of the verilog code for the TPC application has been written and complied all the way through to post place and route simulation. This milestone shows that the design will work, and the work now will focus on debugging the design and making it more robust.

The initial design of the FPGA code is complete and documented. This is the guiding document that is used to write the FPGA code and a reference for users later. The Verilog code that is used to program the FPGA is an involved and complicated task. The first version of this is 100% complete and it has been simulated to verify that it fits in the Virtex 5 chip, that the timing is correct and that the chip is fast enough.
Schematics and a rough part placement (see Figure 14) has been constructed for the digital components. This is the first step to the board layout that will start with the completion of the preamplifier. This complicated layout requires routing over a thousand wires in a card about the size of a business card.

Figure 14: Rough parts layout for the EtherDAQ.

The EtherDAQ Network has made significant progress during the past quarter. ACU received and assembled eight 24-port SFP ethernet concentrator switches with 10-gigabit uplinks (see Figure 15). They have also confirmed Finisar SFP fiber optic transceiver compatibility with the Dell switches. ACU ordered and received a 10-gigabit XFP to PCIe network card. This card was installed in a Linux workstation for testing the 10-gigabit fiber optic ethernet connection to the concentrator switches.

Figure 15: Shown here are the EtherDAQ switches that will be used to route the TPC digital output to the central computer system.
Programs for sending and receiving raw ethernet packets with basic functionality have been written and added to the collaboration's SVN repository. The current emphasis for these programs is to emulate the bandwidth intensive aspects of the primary EtherDAQ network. The programs will be extended to implement the low-level networking protocol of the TPC's FPGA data acquisition cards. Important protocol features such as packet resending have not been implemented yet. The packet receiver program will be further developed as the software layer in between the primary data stream from the TPC's FPGA data acquisition cards the event builder.

A basic DAQ system design has been drawn up for collaboration review and can be seen in Figure 16. Work has continued on finding parameters for event builder and other subsystems.

![NIFTE Data Acquisition Diagram](image)

**Figure 16:** Shown here is the current version of the TPC data acquisition system in schematic form.

The CMC100 USB CAMAC controller driver development has continued. A student has started working on this project and will continue during the fall semester. Device initialization and USB data transfer diagnostic tests have been implemented. Planning and development of CAMAC command stack management are ongoing.

**Preamp**

The preamplifier has been designed and a few channel prototype has been built, see Figure 17. The preamplifier has excellent dynamic range, low noise, and low cross talk. All of the requirements are met with this design and small scale prototype.
The 32 channel production prototype is nearing completion. This ~6 layer board should be ready for production in the following quarter and a full evaluation of the preamp will then be conducted before mass production. The top layer of the layout is shown in Figure 18.

![Preamp Prototype](image)

**Figure 17:** Picture of the preamp prototype.

The 32-channel prototype was successfully reviewed by an engineering team at LLNL. The design was finished and sent to Advanced Circuits for manufacture of the first few prototype boards. The boards have been delivered, and the parts for the production prototype have also been ordered. In the first quarter of the next year we will assemble some of the prototypes and test the design and finalize the production design.

![Preamp Layout](image)

**Figure 18:** Top layer of the preamp layout. This board is about the size of a business card.
MIDAS Evaluation

The design and implementation of most Online Computing components are still in early planning stages. Run control and auxiliary controls have seen the most progress this quarter. The primary focus has been on the MIDAS online data acquisition software package (https://midas.psi.ch). Many components of the MIDAS package are usable as distributed and merely need to be minimally integrated for effective use in the NIFFTE online systems. Other MIDAS components, such as device drivers for uncommon hardware, will need to be customized, extended, or developed by the collaboration.

Evaluation of MIDAS components has continued with regard to frontend and device driver development. Some simple case slow control monitoring capabilities of MIDAS were explored using an RS-232 based multimeter (see Figure 19).

![Figure 19: An example MIDAS status page for run control and monitoring.](image)

A USB2.0 Crate controller has been received by LANL and shipped to ACU for MIDAS integration (see Figure 20). Development of a MIDAS driver for this Cheesecote Mountain CAMAC model CMC100 USB2.0 CAMAC controller has started. The MIDAS driver being developed utilizes existing MIDAS USB support (musb), which is in turn based on libusb, a cross-platform userspace USB library.
Gas Handling and Temperature Control Systems [CSM]

One dominant source of error in the absolute measurement of fission cross sections is the normalization of fission data to the U-235 standard. Any campaign that wants to improve on existing data will have to include a new absolute U-235 measurement. The U-235 reference is used to determine the total neutron beam flux, however this method incurs an error of no less than 1% due to the cross section error. The most promising alternative is the reaction $^1\text{H}(n,n)^1\text{H}$, which is known to 0.2%. This would though require the use of either pure Hydrogen or a very well known admixture as both target and detection gas in the TPC. In order to be not the limiting factor for the precision of the experiment, the hydrogen density will need to be known and kept constant within 0.1%. For calibration purposes, a gas admixture of Kr-83 will be used and in a later stage, one experimental possibility would be the use of a gaseous actinide target. We are planning for a system that allows for the use of three gases being mixed and supplied to the TPC.

Gas Supply System

The main components for the gas system were installed and tested. The tests led to several modifications in the design; which in its final incarnation is displayed below in Figure 21. Filter housing and cartridges have been delivered and tested for pressure and flow restriction. Figure 22 shows the assemble system in the CSM laboratory. They await now tests for HEPA specifications at LANL.
Figure 21: Schematic design of the TPC gas flow system

After first mounting the gas supply system provisionally on particle board, it has now been mounted permanently on an aluminum sheet in preparation for its move and installation at LANL. The control system, based on LabView has been coded to control the valves and to include the MKS gauge readouts displayed in Figure 23.
Additionally, the safety report on the system, which was communicated to Los Alamos National Laboratory and was altered according to the feedback received.

We have also purchased vacuum components, a rest gas analyzer, a test temperature control unit as well as temperature sensors to start work on our tasks in the next budget year in a timely manner.

**Slow Controls**

ACU received the I/O Tech modules ordered by LANL for use in slow control monitoring (see Figure 24). At least one type of each module has been installed in a rack and communication with devices via ethernet has been confirmed. Evaluation so far has shown that some development of how the I/O Ethernet data will be merged into the rest of the data stream will be needed. Simple tests of some of the modules have been completed. The modules include thermocouple readout, 0.0-1.0 Volt and 0.0-10.0 Volt ADC inputs, stress/strain gauge inputs, DAC outputs, and digital I/O for TTL signals. This system will be set up and made operational early next fiscal year.
One ACU project this past quarter has been working on the Axiom m5235 Business Card Controller. This uses a Freescale (formerly Motorola) Coldfire mcf5235 microcontroller. This design is being leveraged from the RHIC PHENIX experiment where it will be used as slow controls on at least two different detectors. The board has several modules that can be used for communication, these are being evaluated as to which is the most appropriate. External communication can be via Ethernet or by building it into a VME crate as a daughter card. This card will permit many different operations, including downloading programs to different DAQ system components, such as FPGA boards.

**Target Design and Fabrication [OSU, INL]**

A well-prepared set of targets is very important for high quality measurements of fission cross sections. Uncertainties in fission cross section measurements with fission chambers can be attributed, in part, to uncertainties in the target mass, non uniformities in the target, surface defects in the targets and surface contaminants in the targets, as well as impure target materials. While the proposed TPC for fission studies will allow detailed corrections for many of these problems, it is of great benefit to start with the highest quality actinide targets.

**Target Design**

We have discussed with group members the question of the required isotopic purity of the materials in the targets. An original suggestion was that the targets should be 99.99% pure. That was later modified to 99.9%. For U-238, this should not be a problem as ordinary “bottle grade” U, as purchased from chemical suppliers is depleted uranium. A typical alpha spectrum of this depleted uranium is shown in Figure 25.
A preliminary investigation has revealed a possible problem with U-235. The primary US supplier of U-235 is Oak Ridge Isotope Sales. Currently this vendor advertises on its website that it will furnish > 98% pure U-235. A telephone conversation with M. Ferren at ORNL reveals the highest enrichment U-235 that is available is 93%, the current output of the Y-12 facility. John Baker has 0.5 g of 99.8% U-235, an amount that is not enough to prepare the needed targets. He has a quote from ORNL for 99.9% enriched material. Higher enrichment materials exist in the research inventories of various laboratories, but their availability depends on negotiations with the various groups. It will be important to establish the isotopic purity of the starting material available for target preparation as soon as possible.

INL management has agreed to pay to move the mass separator and install it in a permanent laboratory, thus it will be available for future use. Additionally, LANL has sent to INL a new front end flight tube with an ion source and quadruple beam steering optics as well as a newer vacuum system which will allow us to eliminate the old oil diffusion pumps.

We prepared our first $^{235}$U target (99.9+% $^{235}$U) and measured the associated alpha particle spectrum. The spectrum is dominated by the $^{234}$U impurity (92% of the activity). Previous work had shown that with $^{238}$U targets, the $^{234}$U activity was the same as the $^{238}$U activity (due to secular equilibrium.) One concludes that when the TPC is used to measure the tracks of the alpha particles emitted from the targets to determine target properties, the tracking will be with the $^{234}$U impurities in the target rather than the primary nuclides. This curiosity should not represent a problem.

We began work on multi-nuclide targets that allow the simultaneous measurement of the cross sections for neutron induced fission of several different nuclides by utilizing...
the ability of the TPC to track the origin of the fission event. The initial test design is to have a 3-leaf clover with one leaf being $^{232}$Th, one leaf $^{238}$U and one blank leaf.

**Gaseous Plutonium Targets**

The original TPC proposal discusses the possibility of using a gaseous actinide target for the TPC. This type of target would reduce the corrections for energy loss in backing materials and allow easy detection of both fragments from a fission event. A suggestion was made that one should consider the use of plutonium hexacarbonyl (Pu (CO)$_6$) as a possible gaseous compound in this regard. This suggestion has been discussed before in the context of the Manhattan Project, where several gaseous compounds of uranium, including uranium hexacarbonyl (U (CO)$_6$) were evaluated for potential use in isotopic enrichment. This research, as well as other post WWII research on this subject was summarized in a review article by Grinberg where it was stated that “synthesis of uranium hexacarbonyl … is impossible. Such compd. probably does not exist.” Subsequently, matrix isolation techniques were used to isolate uranium hexacarbonyl (U (CO)$_6$). It was found that the decomposition temperature of this compound was 30 K, a number that is consistent with the earlier reports of the non-existence of this compound. More recently, in a study of laser ablated U atoms, one found evidence for the existence of a spectroscopic line at 1976 cm$^{-1}$, reflecting the formation of a uranium carbonyl bond. One concludes that the hexacarbonyl derivatives of the actinides are not stable enough to be useful as gaseous targets.

If a gaseous compound of plutonium is to be prepared and used as a nuclear target, it seems clear that one of the primary candidates must be (1, 1, 1, 5, 5, 5-hexafluoro-2, 4-pentanedionato) plutonium, or more casually described as plutonium hexafluoroacetylacetonate. The structure of the basic bidentate ligand, hexafluoroacetylacetonate, is shown in Figure 26. It is well known that β-diketonates of this type form very stable, easy prepared complexes of all the actinide elements. These compounds are routinely used in gas chromatography of the actinides. At room temperature, they are liquids, prepared by solvent extraction of the metals from aqueous solution. Typically they are vaporized in the injection cell of a gas chromatograph beginning at temperatures or about 100 °C and being held at 200-300 °C in the chromatographic column. They are currently being studied for their utility in gas chromatographic studies of the trans-fermium elements.

**Figure 26.** The basic structure of the hexafluoroacetylacetonate (hfa) ligand.

Despite the relative ease of target preparation, there are several severe disadvantages of the use of such gaseous compounds as targets for a TPC. As stated above, to insure the compounds remain in the gaseous state, they must be...
held at 200-300 °C and all surfaces in contact with the target must also be at this temperature. We believe this means that several critical elements of the TPC must be able to withstand the rigors of a high operating temperature. Based upon our previous experience of working in a storage ring where similar constraints were applied to detectors and electronics, this precludes the use of epoxy, many resins, solder, non-ceramic cables, etc. This constraint adds to the difficulty of construction of the device. Perhaps the most challenging aspect of the use of a gaseous Pu target relates to the radiation safety problems posed by such a target. The target is obviously a long-lived radioactive gas that is an alpha-emitter. The target and detector will have to be used in a glove box or similar enclosure with adequate attention being given to the emitted gases. Any rupture of a gas containment structure could have significant radiological consequences.

We consider this report and the presentation of these items at the January collaboration meeting to be a fulfillment of our base charge to “Investigate the gaseous Pu target and make a formal report to the group”.

**Target Fabrication**

The OSU health physics group has made application to the State of Oregon to extend our SNM license to include the quantities of $^{239}$Pu needed to prepare the TPC targets. This extension was needed because the work of other PIs on the OSU campus had nearly exhausted the allowed inventory.

We have made an extensive set of tests of the molecular plating of actinide solutions following typical cleanup chemistry to optimize the amounts of acid and water needed to get good plating conditions. This tuning of the molecular plating should be useful in the preparation of targets of the exotic actinides where small quantities of materials are available and plating yields must exceed 90%. We have taken some photomicrographs of depleted $^{238}$U foils we prepared by molecular plating and the gross uniformity is acceptable (Figure 1). We have examined the detailed uniformity of this target using alpha spectroscopy. Over the anticipated 1 cm beam diameter, there is a 10±5 % variation of the target thickness. Over the entire 2 cm diameter of the target, the center to edge non-uniformity is 3.7%. In summary, the overall uniformity is ok, but there are hills and valleys in the thickness profile.

![Figure 27: A 1 mm² area of a $^{238}$U target prepared by molecular plating.](image)
We made a set of measurements to characterize the variation in thickness in an evaporated depleted $^{238}$U target. A contour plot of the thickness variation over the surface of the 2 cm diameter target active area is shown below.

Figure 28: A contour plot of the thickness variations over a 2 cm diameter evaporated target surface.

Over the anticipated 1 cm beam diameter, there is a 14% variation of the target thickness while over the entire area of the target the variation in thickness is about 30%. This variation in target thickness is unacceptable. Note the evaporation geometry involves an 8 cm distance between the evaporation boat and the substrate. Thus, from geometric considerations, one would only expect a 4% variation in thickness from the center to the edge of the target. It appears the evaporation boat is producing a “beam” of molecules rather than emitting them isotropically. To solve this problem, we adopted a “four source” evaporation geometry, i.e., evaporating material on the target from four spatially separated sources to improve uniformity. The resulting targets show a variation of < 1.5% in thickness over the anticipated 1 cm beam diameter.

29g of high purity $^{235}$U (99.68% and 99.91%) were located at LLNL and the process has started to ship this to Oregon University.

INL has continued collaborating with Oregon State University in regard to the development of TPC targets and foils. ORNL encountered an operational problem and was unable to ship the ordered actinide target material. We believe that the material will be shipped early in the new fiscal year. In order to supplement this order, OSU, LLNL and INL has found other supplies of very highly enriched $^{235}$U, $^{239}$Pu and $^{243}$Am, 99.89, 99.99 and 99.8 percent enriched, respectively.
**Target preparation**

We coated (with a 2 cm diameter deposit of ThF$_4$) a large (7 inch diameter) stainless steel target from INL and shipped the coated target to INL for further evaluation. In the process, we constructed apparatus to mount and coat these large area foils in our evaporators. In Figure 29, we show such a target with a deposit on it.

![Figure 29: Large area stainless steel target with ThF$_4$ deposit.](image)

We have prepared 3 new U-238 targets. (In Figure 30, we show a typical target. The green UF$_4$ deposit is clearly visible.) The areal density of these targets ranges from 200-300 µg/cm$^2$. The isotopic purity of the targets was determined by alpha spectroscopy and is 99.86% U-238, 0.1395% U-235 and a small amount of U-234 (from secular equilibrium). We think these targets (and the starting material used to prepare them) meet the general criterion set forth in group discussions of 99.9% pure material. (See above for further discussion of this issue). The targets have been given to our health physics staff for shipment to LANL. One of the targets has an off-center deposit, which makes it useless for a real experiment but allows it to be used for testing purposes.

![Figure 30: A typical U-238 target. The green UF$_4$ deposit is clearly visible.](image)
252 Cf “response” target

By the term 252 Cf “response target”, we understand that one means a suitable 252 Cf source for measuring the response of a detector to 252 Cf fission fragments. We outlined four possible strategies for the preparation of such a 252 Cf source. They are:

- Preparation of 0.1-1 nCi 252 Cf sources by self transfer from a mother source. These non-coated sources can be prepared on thin or thick backings (allowing their use in either a single or double fragment detection scheme). We can prepare such sources for anyone who wants one (at no charge) and would provide a complete assay of the source as to activity and composition as part of the source preparation.

- Preparation of these 0.1-1 nCi 252 Cf sources by a commercial supplier, Isotope Products, of Burbank, CA. The Isotopes Products sources are prepared with a Au coating to reduce self-transfer on a thick backing. They cost about $1700 each and have a nominal activity given on the source.

- Commercial 1-50 uCi sources prepared on thick backings, with a price range of $2500-$3500.

- 1-10 uCi sources prepared by molecular plating on either thin or thick backings.

The group indicated their preference for a source with an activity of about 1 uCi prepared on a thin backing. Since this is to be a one-of-a-kind source, John Baker of INL volunteered to provide it. We investigated whether we can make sources resembling this by self-transfer from a hot mother source, but found these self-transfer sources will be limited to a few nCi. We prepared two ~1 nCi 252 Cf sources on thin backings by self transfer for use by the project.

We cautioned the group about our recent experience with 252 Cf sources, which have been 70% 252 Cf, 20% 250 Cf and 10% 249 Cf. A new shipment of “252 Cf” from Isotope Products showed the continued existence of this problem. These impurities become important in quantitative calibrations of detectors but are easy to document and determine by alpha-particle spectroscopy.

Target Backing Materials

We plan on fabricating the targets for the TPC using either molecular plating or vacuum deposition. Molecular plating is 60-85% efficient while vacuum deposition is < 10% efficient. Past experience indicates the best uniformity is achieved using vacuum deposition, while molecular plating is preferred for those nuclei where the amount of material is limited. Molecular plating requires the use of a conductive backing material. For the primary targets, 235 U, 238 U and 239 Pu, we do not expect to be limited by the amount of material and thus we plan on using vacuum deposition as we believe the uniformity of the target is better.

We evaluated C, Al, Ti and polyimide as possible target backing materials. Nominal thicknesses of these materials that appear to be suitable are 0.54 mg/cm² Al, 0.050-0.1 mg/cm² C, 2.3 mg/cm² Ti and 0.050-0.100 mg/cm² polyimide coated with 0.050 mg/cm² Au (to render the material conductive). Samples of these backing were shown at the collaboration meeting. The energy loss of a 80 MeV 80 Br fission
fragment in passing through these backing materials is 18.2, 8.0, 54 and 4.9 MeV, respectively for the Al, C, Ti and polyimide backings. Polyimide is typically 72.1%C, 2.8%H, 7.7%N and 17.5%O by weight, but has a variable composition. It is very fragile. Because fragment energy loss in such a material is difficult to estimate because of the variable composition and the limitations of connectivity relationships in estimating dE/dx, polyimide is not recommended as a target backing. We recommend (and the group seemed to accept) the use of 0.100 mg/cm² C as the target backing.

To further evaluate these 0.1 mg/cm² C foils as target backings, we performed Atomic Force Microscopy on some samples of this material. Figure 31 and Figure 32 show some typical scans of the samples with varying spatial resolution. The rms surface roughness of the foils (1 µ x 1 µ scan) was 7.4 nm where the average thickness of the backing foil is 440 nm. This is a very uniform foil and is much better than we usually see for polished metal foils where the average surface roughness is ~17 nm. Two large area scans (10 µ x 10 µ) were made of the foils and showed a very smooth surface with a few visible “mountains.” The largest mountain observed had a height of ~500 nm.

Figure 31. High resolution scan (1 micron x 1 micron) of the target backing material.

Figure 32. Low resolution (10 micron x 10 micron) scan of the target backing material.
Some interest has been expressed in the use of carbon nanotube foils of thicknesses less than 10 $\mu$g/cm$^2$. These foils are known to be quite robust\textsuperscript{xii}. These foils have been extensively tested at ORNL for use as stripper foils for HRIBF. We contacted M. Meigs of ORNL who reported their experience with these foils as being robust, but non-uniform and containing holes. We contacted D. Shapira of ORNL who verified the Meigs report and further suggested that with a few hundred volts applied to the foils, they tended to spark, releasing C dust. Shapira has agreed to send us some typical foils so that we may further evaluate them as target backings. We consider this report to be a formal fulfillment of the initial charge to us to investigate and report on possible target backings although we will evaluate the carbon nanotube foils.

**Target shipping issues**

We have designed and tested a standard shipping container for shipment of the actinide targets to Los Alamos. The design was developed by the Micromatter Corporation and is similar to containers we have built and used for many years. A picture of the target shipping container is shown in Figure 33. The targets are held under vacuum for shipping in a transparent container in which damage to the targets is readily visible. The targets are held in grooves in plastic holders by 2-56 Allen head set screws. (A 2-56 Allen wrench is taped to the outside of the container for use in target removal from the shipping container.) A set of standard instructions for recovery of the targets from the container is attached to the outside of the container and hopefully is read prior to recovery of the targets. Upon receipt of the container, the targets should be removed from the container as it is not a suitable container for long term storage of targets and the container is returned to Oregon State University for further use. Based upon past experience, we expect 80-90% of the targets will survive shipping.

To test the containers, we proposed a phased testing program, beginning with non-radioactive targets and then escalating to radioactive targets of higher specific activity. In an initial test of shipping non-radioactive targets to LANL, a target backing came loose from its mount and another target was destroyed in handling at LANL. We redesigned the way the target backings (0.1 mg/cm$^2$ C) were affixed to the target support by gluing them down with carbon conductive cement. A subsequent shipping test showed no problems with the target backing and no breakage upon removal from the shipping container. Targets with deposits of ThF$_4$ are being prepared for the final tests of shipping radioactive targets to LANL.
A new strategy was adopted for the shipment of radioactive targets to LANL due to difficulties we experienced with previous shipping attempts. We ship the prepared targets to INL who then ships them on to LANL. A shipment of two “test” depleted $^{238}$U TPC targets was sent successfully to INL and they successfully shipped them to LANL. The OSU-INL shipment took about 1 day to complete and the INL-LANL shipment took about 3 weeks to obtain the necessary permissions prior to shipping. The $^{238}$U targets were received intact at LANL. We believe this represents completion of the milestone that we demonstrate our ability to ship radioactive targets to LANL.

Two “production” $^{238}$U targets were prepared using the “four source” technique. The average thicknesses of these targets were 144.6 and 134.9 $\mu$g/cm$^2$. The variations in thickness of the targets over the 1 cm beam spot diameter were less than 1.5%. The targets were packaged for shipment and sent to INL for shipment to LANL. We consider the preparation of these targets to be a routine matter now involving about ten days to prepare a target, and to measure its thickness and uniformity.

INL has identified a laboratory for the mass separator and it should be moved in the first quarter of FY 2009, following installation of utilities in the laboratory at the Material and Fuels Complex. INL received the mass separator equipment from LANL.

**TPC Software**

**Scope**

The TPC Software effort will include online and offline coding, FPGA programming for the data acquisition system, and simulation.

In an extension of the modeling effort, a mock data challenge will be produced. The idea behind the mock data challenge is to run the virtual experiment with enough detail to understand the impact of parameter choices - from collimation to pad layouts. This will entail running the full 4-D model of the experiment in the experimental facility, and the fission as well as background events are scored. These results will be processed through the electronics system by use of a pulse generation...
system and analyzed by the online software. This model will allow for the optimization of several experimental parameters such as beam flux, collimation, shielding, gas pressure, gas temperature, etc. This will also give the users the ability to study and optimize the design parameters of the TPC and the front-end electronics, including the data sparsification algorithms.

**Highlights**

- MIDAS data acquisition and control software has been evaluated and appears to be a good choice for use in this experiment.
- Offline software design specification developed and implemented, including documentation.
- A TPC hit-finder code and a two-dimensional TPC cluster finder code have been written, tested and installed in the SVN repository. Work continued on the KALMAN track reconstruction code.
- TPCModule base class written with single API for all inherited classes: TPCClusterFinder, TPCHitFinder, TPCTrackFinder. All new reconstruction/calibration modules should inherit from TPCModule to inherit full functionality.
- New classes introduced to NIFFTE software to handle I/O for ROOT file formats (NiffteRootData, NiffteTimeStamp, NiffteDataBucket, NiffteRootIO, NiffteDataHandle, NiffteRootHeader) tested, validated and committed to code repository.
- New persistent data storage classes introduced to NIFFTE software that inherit ROOT I/O streamer capabilities (NiffteTPCDigit, NiffteTPCCluster, NiffteTPCHit, NiffteTPCTrack) tested, validated and committed to code repository.
- Conversion methods between transient/persistent objects included in persistent data classes and NiffteReconstructor to handle interface to TPC library transient data objects.
- NiffteReconstructor updated to read/write to and from both ASCII and ROOT file formats. In the case of ASCII files, only digits are read/written, whereas in the case of a ROOT file, all objects can be read/written.
- Doxygen code documentation system configuration file created for NIFFTE project. Software documentation is available.
- A successful initial collimator design has been completed based on a highly detailed MCNPX model of the LANL facility and is one of the milestones for this project this year. New design criteria have been established in meetings with LANL that will be incorporated into the follow-on design.
- A complete GEANT4 simulation of the TPC sensitive volume has been created and tested. The simulation includes transverse and longitudinal diffusion, digital time latching, charge sharing and pedestal noise.
- Programs for sending and receiving raw ethernet packets to and from the EtherDAQ switch with basic functionality have been written and added to the collaboration's SVN repository.
- A timeline for the Mock Data Challenge has been developed to insure that this important FY09 milestone is accomplished.
Online Software [ACU]

The portion of this experiment's software library that is used during the data taking is called the online software. The features that fall within this category include: data receiver, event builder, data cataloging and storage, run control, on-the-fly data inspection, data base management, electronic log book, and remote experiment monitoring and control. Some of this software is available and only needs to installed and maintained on the online computers, other software will have to be written and maintained in the collaboration subversion library. All written software will be written following a modular design for reusability in C++. In addition, the online software team will take on the role of administer for the online computers.

EtherDAQ software

The CMC100 USB CAMAC controller driver development has continued. A student has started working on this project and will continue during the fall semester. Device initialization and USB data transfer diagnostic tests have been implemented. Planning and development of CAMAC command stack management are ongoing.

Programs for sending and receiving raw ethernet packets with basic functionality have been written and added to the collaboration's SVN repository. The current emphasis for these programs is to emulate the bandwidth intensive aspects of the primary EtherDAQ network. The programs will be extended to implement the low-level networking protocol of the FPGA data acquisition cards. Important protocol features such as packet resending have not been implemented yet. The packet receiver program will be further developed as the software layer in between the primary data stream from the FPGA data acquisition cards to the computer based event builder.

Offline Software [CalPoly, LLNL]

The thrust of this task is to transform the data from their raw form to final calibrated results, which requires a complete data analysis chain. The online software required to perform this analysis must be designed, organized, written and documented. In order to achieve maximum flexibility, the design should focus on providing simple interfaces within a modular framework. For ease of use by collaborating experimenters, the software should also be well documented and maintained in a central repository available to the entire collaboration.

The effort to develop the computing framework and offline software centered on meeting three major milestones in the second quarter before coding could begin:

1) establishing the common set of tools to be used for the software,
2) developing a software design specification, and
3) acquiring and configuring the hardware to be used for software development.

Details on the fulfillment of these milestones are outlined below.

Development of the software framework was undertaken in the third quarter. At Cal Poly, the common logging tool and basic framework design were coded and tested, and an undergraduate student was employed to begin writing a traditional two-dimensional cluster finder, hit finder and tracker. Simultaneously, undergraduate
students from Abilene Christian University stationed at Los Alamos began writing more advanced reconstruction algorithms to process simulation data.

Development of the software framework progressed steadily during the fourth quarter. The first version of the software and initial documentation was released to the collaboration on August 9, 2008. Development the traditional cluster and hit finders continued, utilizing the GNU Scientific Library (gsl) for function minimization, as well as improvements in the framework with updates to simplify the interface between the NIFFTE-specific code and the TPC library and introducing a complete set of new I/O classes to handle ROOT file formats. These updates make the integration of the other analysis algorithms easier to accomplish. Development of the traditional track-finder, integration of the simulation code and documentation will continue in the first quarter of the new fiscal year.

Common Computing Tools

Before selecting tools or setting of specific guidelines, a review of modern standards in high-energy physics software was undertaken in January, 2008. This involved studying the software and computing models used by the PHENIX and STAR experiments at RHIC, LHC-b and ALICE at the CERN LHC, E907 at Fermilab and BaBar at SLAC. Almost all of these experiments utilize the C++ language and the ROOT system for data storage (persistency), histogramming and analysis. The exception to this rule is LHC-b, which has chosen to separate the memory-resident or transient data from the persistent data with no explicit dependence on ROOT software libraries. Based on this review, the NIFFTE collaboration opted to adopt a hybrid software model using C++ with internal transient data objects with interfaces to ROOT-based persistency objects. Further information on how this model is to be implemented are provided in the software design specification.

In addition to the coding language and data framework, the review of existing HEP software motivated the adoption of open source tools such as PostgreSQL as the database for holding detector conditions data and the adoption of a set of coding conventions and standards for the writing and documenting of NIFFTE software. The ALICE experiment ruleset was chosen as the template for NIFFTE. ALICE employs an automatic rule-checker to enforce compliance with coding standards and NIFFTE obtained permission from the authors of the rule-checker to adapt it for NIFFTE project software.

A table of external computing tools and libraries to be used in the NIFFTE software is presented in Table 1. These choices reflect our consideration of the combined experience of the HEP community and will allow NIFFTE to develop completely open-source software based on well-documented and supported tools.

Table 1. External computing tools/libraries adopted by NIFFTE.

<table>
<thead>
<tr>
<th>Supported OS</th>
<th>MacOSX, Linux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coding Language</td>
<td>C++ (only legacy fortran ok if wrapped by C++)</td>
</tr>
<tr>
<td>Build system</td>
<td>GNU automake</td>
</tr>
<tr>
<td>Parallelization</td>
<td>OpenMPI</td>
</tr>
<tr>
<td>Configuration language</td>
<td>XML</td>
</tr>
<tr>
<td>------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>XML Parser</td>
<td>xerces-c</td>
</tr>
<tr>
<td>Database</td>
<td>PostgreSQL</td>
</tr>
<tr>
<td>Persistent Data</td>
<td>ROOT</td>
</tr>
<tr>
<td>Geometry (detector description)</td>
<td>TGeo (ROOT)</td>
</tr>
<tr>
<td>Visualization</td>
<td>ROOT with OpenGL</td>
</tr>
<tr>
<td>Code documentation</td>
<td>Doxygen</td>
</tr>
<tr>
<td>Version control</td>
<td>Subversion</td>
</tr>
</tbody>
</table>

A table of external computing tools and libraries to be used in the NIFFTE software is presented in Table 1. These choices reflect our consideration of the combined experience of the HEP community and will allow NIFFTE to develop completely open-source software based on well-documented and supported tools.

**Software Design Specification**

The development of a software design specification is the first step in the creation of a new software library. This involves defining the input and output data objects to be processed, outlining the list of algorithms to perform the processing, establishing the steering model for controlling the algorithms and data interfaces, and developing the list of C++ classes that will form the backbone of the software. The first version of the software design specification (version 0.0) was developed and presented to the collaboration in March 2008 for review and feedback. Based on that review, a revised specification was developed. Details of the version 1.0 specification are presented here.

The major changes to the original design proposal are based on separating the TPC reconstruction libraries from the NIFFTE-specific implementation and incorporating the LHC-b model of separating transient data from persistent data. These changes accomplish two important goals. First, the isolation of the TPC library from the NIFFTE software will enable the TPC code to be re-used for other applications with minimal dependence on NIFFTE-specific design considerations. Second, the separation of the transient and persistent data will allow for much simpler swapping of persistency models later, if a better tool becomes available or limitations imposed by the ROOT system necessitate such a change. Although these revisions come with some additional overhead, they provide the level of desired flexibility that was listed as one of the original goals of the software design.

Listed below are the key components of the TPC and NIFFTE libraries. Figure 34 shows a diagram of the program flow during NIFFTE reconstruction, from job configuration, and data I/O to TPC reconstruction algorithms. A user specifies the modules and data to include in reconstruction with an XML configuration file. The NiffteReconstructor opens and reads the corresponding input files and database parameters, calls the requested list of algorithms and finally transfers the output data from the transient objects to persistent ones and writes the data summary table (DST) to disk. All actions, debug info and logging messages are written to a log file on disk. Coding of the base classes for NIFFTE reconstruction are the focus of the third quarter effort (April-June, 2008) while concrete algorithm implementations and
processing of simulated data will be the focus of fourth quarter efforts (July-October, 2008).

Figure 34: Diagram showing the flow for NIFFTE event reconstruction.

TPC Library

- Transient Data Objects
  - TPCDigit - raw data, stores individual unit of TPC information, voxel and ADC values
  - TPCCluster - result of cluster finding, stores list of neighboring TPCDigits forming a cluster
  - TPCHit - result of hit finding, stores list of neighboring TPCDigits forming hit, information on center of gravity, total hit energy deposition
  - TPCTrack - result of track finding/fitting, stores list of TPCHits forming track, track fit parameters, pid information

- Reconstruction Modules
  - TPCClusterFinder - sorts through TPCDigits to find contiguous clusters of digits
TPCHitFinder - sorts through TPCClusters to find contiguous clusters, fits them for local maxima and minima, determines center of gravity, total deposited energy

TPCTrackFinder - performs pattern recognition on list of hits, clusters or digits to find tracks

TPCTrackFitter - fits track candidates with appropriate geometric model, determines track parameters, range, dE/dx

TPCPid - uses range and dE/dx information to determine most probable identity of track

NIFFTE Library

- Common Support Classes
  - NiffteMessage - message logging system to record debug info, actions
  - NifftePhysicalConstants - all physical constants used in software stored here
  - NiffteConditionsIO - reads/writes database info

- Steering/Program Control
  - NiffteReconstructor - main steering class for reconstruction
  - NiffteRecoConfig - reads/parses XML configuration file for reconstruction

- Offline Data I/O
  - NiffteRawIO - reads/writes raw data stream, populates TPCDigits
  - NiffteSimIO - reads/writes simulated data, populates TPCDigits, MCTruth
  - NiffteDSTIO - reads/writes data summary table of reconstructed data used for analysis

- Persistent Data Objects
  - NiffteRun - stores global run information
  - NiffteConditions - stores information on conditions data used in reconstruction
  - NiffteMCTruth - stores trajectory and pid information of MC particles from simulation
  - NiffteEvent - stores information on current “event”
  - NiffteTPCTracks - stores the array of tracks associated with the current “event”
  - NiffteTPCHIts - stores the hits associated to the tracks of the current “event”

- Calibrator Modules
• Calibration Algorithms
  • NiftteTPCLaserCalibMaker - creates calibration data from laser tracks
  • NiftteTPCKrCalibMaker - creates calibration data from Kr-83 calibration runs

• Conditions Data
  • NiftteTPCDigitCalibTable - db table for holding digit calibration info
  • NiftteTPCHitCalibTable - db table for holding hit/cluster calibration info
  • NiftteTPCTrackCalibTable - db table for holding track calibration info

Framework development

The basic components of the offline software framework, including the TPC library application programming interface (API), the common message logger, a simple ASCII I/O class and the reconstruction configuration and steering classes were written and tested. The structure of the code directories was established and comprehensive, shell-neutral setup scripts which create the NIFFTE environment ($NIFFTE/setup.niffte) and perform the building of the compiled code ($NIFFTE/autogen.sh) were developed. The scripts and code have been tested on both Ubuntu linux and Mac OS X, and the only assumptions are 1) that the developer/user has set the environment variable $NIFFTE to point to the installation directory and 2) the required external packages have been installed in default locations on the system. See Table 2 for a list of the external packages currently required by the framework (and installed on nuclear.calpoly.edu). This list will grow and evolve as the project proceeds, but the code documentation will always indicate the most recent supported versions.

<table>
<thead>
<tr>
<th>External package</th>
<th>Version</th>
<th>Default location</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNU build system</td>
<td></td>
<td>/usr/bin</td>
<td><a href="http://www.gnu.org/software/autoconf/">http://www.gnu.org/software/autoconf/</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Note: Should be included by default)</td>
</tr>
<tr>
<td>Xerces-c</td>
<td>2.8.0</td>
<td>$XERCESCROOT</td>
<td><a href="http://xerces.apache.org/xerces-c/">http://xerces.apache.org/xerces-c/</a></td>
</tr>
<tr>
<td>ROOT</td>
<td>5.19.02</td>
<td>$ROOTSYS</td>
<td><a href="http://root.cern.ch/">http://root.cern.ch/</a></td>
</tr>
</tbody>
</table>

Table 2: External library versions and default locations required by the software framework.

The TPC API includes the skeleton classes TPCDigit, TPCCluster, TPCHit, TPCTrack, TPCClusterFinder, TPCHitFinder and TPCTrackFinder. These form the
base classes from which subsequent implementations should inherit. The API is currently very simple to allow for more detailed development as specific algorithms are designed and incorporated into the library. During the development of the TPC library API, it was realized that the message logging capabilities of NiffteLog would be extremely useful within the TPC library. In order to preserve the code separation desired between the TPC library and NIFFTE library, the NiffteLog class was renamed MsgLog. This class will continue to reside in the $NIFFTE/common directory but will also be included with the TPC library separate release.

Ryuho Kudo, a Cal Poly Computer Engineering undergraduate, joined the project as a student assistant in June and has since completed writing a two-dimensional TPC cluster finder. The 2D cluster finder is a traditional TPC reconstruction approach that divides the drift volume into Nbucket independent planes of row and column information and performs a nearest neighbor search over the plane to find clusters of digits. These digits form the input to a 2D hit finder which then performs deconvolution and signal fitting to determine the position and total signal. The list of hits is then fed to the track finder to join hits from the Nbucket drift planes into track candidates which can be fit by the track fitter. The development of the hitfinder and tracker are in progress and will be completed during the fourth quarter. These efforts complement those of the ACU students working at Los Alamos, who are using more modern methods, including the Hough Transform, to perform tracking on simulation data. Our pursuit of multiple reconstruction techniques will allow for algorithm vetting and systematic uncertainty evaluation of the reconstruction chain.

The classes NiffteRecoConfig and NiffteReconstructor were written to handle configuration and steering of reconstruction jobs. NiffteRecoConfig uses the xerces-c XML parser libraries to read and parse an XML configuration file which currently stores the list of reconstruction modules to be run. Eventually it will also store any user-specified parameters of those modules as well. In the main program, a NiffteReconstructor object is the primary interface to the reconstruction chain. The primary object constructor takes the XML config file, an input data file and an output data file as arguments to set up the reconstruction job. Using the list of requested modules from the config file parsed by a NiffteRecoConfig object, the NiffteReconstructor registers the modules to be run and loads the input data.

The input data passed to the NiffteReconstructor can depend on the list of modules to be run. At the moment, the code is available to receive a list of TPCDigits, but in the future this will be extended to take in any of the basic components - digits, clusters, hits or tracks for further processing. Based on the type of input file specified (currently just ASCII files with extension *.dat), the NiffteReconstructor creates an instance of a data I/O object and fills a container (STL vector) of TPCDigits. The NiffteReconstructor owns this container and can pass it to the reconstruction modules that will process the digits.

The $NIFFTE/dataIO directory holds the various I/O classes. Currently implemented is NiffteAsciiIO, which can read or write a file of type *.dat that contains a list of TPCDigits in the format row column bucket ADC. Other data I/O classes will be written for reading/writing the NIFFTE raw data files, ROOT TTrees and TNtuples.

**Libraries, main and ROOT interface**

The current implementation of the framework creates a set of shared object libraries for each of the subdirectories in $NIFFTE: libreco.so, libtpc.so, libcommon.so, and
libdataIO.so. These libraries are compiled together with a main.cc to create a single executable called niffte. The main program currently requires three inputs to execute or generates a usage message and exits.

Usage: niffte -c <configfile> -i <input> -o <outputfile>

Example files $NIFFTE/testconfig.xml and $NIFFTE/testdata.dat are provided. The main program creates a NiffteReconstructor object, passing the expected arguments to the reco object and runs the reconstruction:

```cpp
NiffteReconstructor* reco = new NiffteReconstructor(cfgfile,infile,outfile);
reco->RunReco();
```

However, this is not the only way to execute the reconstruction software. One can also load the shared object libraries into a ROOT session (interactive or batch) and create and run a NiffteReconstructor job. This functionality, which requires the creation of ROOT dictionary files for the NIFFTE code library, is incorporated into the build system and is available by default to the user.

**Track Reconstruction Effort**

ACU students were involved in the track reconstruction effort while working at LANL over the summer term. The goal of this effort was to provide a basic track reconstruction package to complement their TPC simulation effort in providing timely design impact feedback. The sensitive volume simulations (more details in the appropriate section) and the tracking effort provide a beginning-to-end accomplishment for this project and will allow us to study in great detail, the impact of design choices on important measurement requirements, such as tracking and timing resolutions, efficiencies and background rejection.

This experiment has borrowed a number of ideas from high energy physics, including the TPC itself. It should come as no surprise that we will also borrow from them to reconstruct the fission events in our detector. In a typical high energy experiment, there are usually some number of sub-detector systems, many of them nested between one another. The data in the sub-detectors are usually processed independently, into detector specific clusters, or hits, and then hits strung together to form tracklets. A global track reconstruction program will typically be used to combine the smaller tracklets into complete tracks. A final pass over the tracks is usually made to calculate the best tracking parameters and errors using a Kalman filter. The Kalman filter provides information to the track fitter about the detector itself and removes biases that accumulate and result in biases and improperly calculated uncertainties.

It is our goal to use a Kalman filter in a final tracking pass to optimize the track pointing resolution and potentially for particle ID. However, there are some simplifications in our application. For instance, there is only one detector volume and
primarily only one scattering material (the TPC gas). Also, there are very few tracks in the detector, particularly for U-235 and U-238 measurements. Therefore, there are some simplifications we can make to the high energy paradigm. The first one is in track finding. Given that we have a single detector volume, we may forego a clustering algorithm and tracklet forming code. Specifically, two different approaches were used to find tracks in the fission TPC – a Hough transform and a binary space partitioning algorithm.

The Hough transform can be considered a brute force attempt at finding tracks. The algorithm uses all the hits in the detector to form track hypotheses in a 3-D space. The probability density increases in the regions around the true track parameters. This algorithm works best on certain types of data, or hit topologies. Figure 35 shows the input and output data for a typical track finder. The space-point data are represented by boxes. The size of a box indicates the amount of charge measured. Also shown is the resulting track and the two different 2-D representations.

Figure 35: Here is a graphic representation of the input and outputs to the Hough transform. The boxes represent raw data. The found track, along with the projections are also shown.

Two variants of the Hough Transform were tried on raw data, the first simply drew all possible lines in 3 dimensions through each of the space points. The lines were parameterized and recreated on a histogram thus performing the 'transform'. The bins with the highest frequency were used to recreate the track.
The second variant of the Hough transform calculates a 3-D track probability density by simply using all possible combinatorics of the available space-points and a straight-line track hypothesis. Weights are assigned to each track hypothesis based on the number of hits consistent with it. Figure 36 shows a pair of 2-D representations from the Hough calculation.

The axes used in this calculation are the angles of the track in either the x-y or x-z plane and the distance from origin. The results in these plots are derived from the data shown in Figure 35. Two things are clear – some tuning will be required to get this transform to work best with these data and that there are a lot of calculations being performed for a simple track. It easy to imagine that sparse, well-separated data lends itself to this calculation but the TPC data is just the opposite. Some simplification arises if one invokes a clustering algorithm before the Hough transform but even that has problems, particularly for tracks that remain within clustering layers. To complete the track finding, one would select the most probable hypothesis and then remove those hits associated with that track and then run the algorithm again. An illustration of the method is shown in Figure 37.

Figure 36: The Hough transform provides weights to track hypotheses in angle and perpendicular distance from origin in 3-D. These are Hough results in the x-y (left) and x-z (right) plane track projection.
Figure 37: Illustration of the Hough transformation in 2 dimensions.
Another method of finding tracks in 3 dimensions is to calculate the moments of the charge distribution measured in the TPC. Figure 38 shows a pair of color-coded tracks from a GEANT4 simulation of the TPC. The measured 3-D charge distribution is used to calculate the mean, variance, skewness and kurtosis ($0^{th}$, $1^{st}$, $2^{nd}$ and $3^{rd}$ moments) of the volume. Track finding is achieved by recursively dividing the TPC space along the axes of least distribution until the variance becomes less than the expected width of a track (Figure 39). Once a volume contains only a single track, the moment calculation is used to initiate a track fit. This method has proven to be more efficient than the Hough Transform.

Figure 38: Shown here is a graphic representation of a pair of tracks in the TPC and the results of a moments calculation using the deposited charge. The plane represented by the axes of least distribution are used to partition the event into spaces containing individual tracks.
Figure 39: Illustration of binary space partitioning in 2 dimensions.
Once a group of hits have been collected and identified as a track, the information is passed to a Kalmanized track fitter. The Kalman filter is a recursive track estimator that treats the measurements sequentially, adding one hit after another. The state vector that represents the track information is updated after each recursion, or step. The error matrices also evolve as information is added in each step, providing improved confidence intervals for each hit, making it easy to remove outliers. Figure 40 shows how the Kalman fit progresses and updates the tracking uncertainties.

Figure 40: The Kalman filter progresses through the hits, refining the tracking information and tracking errors. Shown here are the prediction and filter steps of the Kalman Filter. The cones represent the uncertainties associated with each measurement layer. The Filter is initialized with large uncertainties represented by the large cone at the beginning of the track.

The Kalman filter consists of three steps that are shown graphically in Figure 41. The hit information is used in a recursive fashion beginning with the first hit on the track. The state vector is predicted at the subsequent hit locations using the currently available information. The filtering process then evolves the propagation, projection and error matrices using the predicted measurement. The state vector is again calculated using the new data. The last pass is smoothing. Upon reaching the end of the track, the points are again predicted and filtered in a backward moving pass to arrive at the best estimates of the initial track parameters.

Figure 41: This graphic shows the basic track fitting evolution from a simple predicted track, through Kalman filtering, and then to the final smoothed track, whose parameters and uncertainties are accurately determined.
TPC Library Interface

In order to simplify the interface to the reconstruction algorithms within the TPC library from the NIFFTERReconstructor, a new set of classes was developed, based on the E907/MIPP model. TPCConfig, TPCConfigParam and TPCConfigTable provide the way to pass configuration parameters from the XML configuration file to the reconstruction modules. The individual TPC reconstruction parameters consist of a name, comment and a collection of data values, all of which must be of a single type. When the TPCRecoConfig parses the XML file, it creates an instance of the TPCConfigTable and TPCConfig objects for each requested reconstruction module, then adds those to the table, which is just a collection of configuration objects.

TPCModule is the base class for all reconstruction modules. It provides a Configure() method to access the configuration information stored in the TPCConfigTable and a set of data access methods,

```cpp
//Methods to pass the data to process into the module
virtual void ConnectDigits(ConstDigVec* digits);
virtual void ConnectClusters(ConstClusVec* clusters);
virtual void ConnectHits(ConstHitVec* hits);
virtual void ConnectTracks(ConstTrackVec* tracks);
```

to connect the input and output data collections owned by the NiffteReconstructor which will be acted upon and filled, respectively. The Run() method of the module performs the actual processing of the data and returns a code indicating success, error or failure. In each case, these methods must be overloaded by the descendent class to perform its specific reconstruction functions. TPCModuleTable holds the collection of registered modules for automatic processing within a reconstruction job. Only those modules registered in the table will be run by the reconstructor.

Data I/O

The most substantial updates to the NIFFTE framework undertaken in the fourth quarter was the development of the classes to handle data I/O for ROOT file formats. The code is based on the ROOT I/O structure of the E907/MIPP experiment and utilizes templated class methods to read and write TClonesArrays and TObjArrays of persistent data objects. The transient data classes defined in the TPC library each have a corresponding persistent data class with ROOT streamer information in order to be read/written to ROOT files. This duplication is not ideal, but necessary, and can provide a way to simplify what information is stored on disk. These classes will evolve as needed to minimize their size while maintaining the needed information. A list of the new classes and their descriptions follows:

- **Persistent data objects**
  - NiffteTPCDigit - Holds row, column, bucket and ADC info for each TPC voxel
• **NiffteTPCCluster** - Holds id, ADCsum, min/max row and column as well as the vector of digits comprising it. This vector will likely be converted to a TRefArray of references to digits stored elsewhere in the ROOT file.

• **NiffteTPCHit** - Holds its own id, the id of the cluster it was formed from, type of cluster, ADC sum of digits comprising it, and the total fitted ADC and 3-D position of the hit with uncertainties determined from the fitter.

• **NiffteTPCTrack** - Currently a placeholder for track information, only stores track id at the moment.

**I/O handling**

• **NiffteDataBucket** - A class for managing a collection of ROOT TFolders and data objects stored either as TClonesArrays or TobjArrays.

• **NiffteTimeStamp** - Holds the time-stamp for a specific ``event'' in NIFFTE data.

• **NiffteRootHeader** - Defines the header information for NIFFTE data, including the run number, software version, timestamp, whether or not this is Monte Carlo or real data, and the ``event'' number, if known.

• **NiffteRootData** - Defines the ``event'' structure for NIFFTE data, consisting of ROOT TFolders to hold data objects according to their type: header, MC, detector simulation, raw data, calibrated data, reconstructed objects and a user scratch area for histograms and other data.

• **NiffteDataHandle** - Provides the interface between the NiffteRootIO object and the ROOT-streamable NiffteRootData object. It is set up to allow for partial I/O of various major components of the NIFFTE data.

• **NiffteRootIO** - Handles the actual I/O of NIFFTE ROOT objects and configuration of the input and output files.

The NiffteReconstructor has two I/O data members: pointers to a NiffteAsciiIO and a NiffteRootIO object. Based on the file extension of the input and output data files passed to the executable at the command line

Usage: niffte -c <configfile> -i <inputfile> (optional: -o <outputfile> -d <debuglevel>)

the reconstructor determines which type of I/O handler to create. If no output file is specified, the reconstructor assumes that ROOT output is desired and creates a default named output file niffte-output.root. If the input file is of the extension *.dat, only digits are read from the file. If the extension is of type *.root, raw digits are read and then depending on the list of registered reconstruction modules, other data types may also be loaded. For example, if the TPCHitFinder is the first requested module, the NiffteRootIO attempts to load clusters from the ROOT file for hitfinding. By contrast, if TPCClusterFinder is the first requested module, any clusters within the file will not be loaded into the transient data object, because the reconstruction job will add newly found clusters to the transient cluster vector, which
would then be written out with both the old and new clusters in it. In a future implementation of the code this may be avoided by allowing for multiple versions of transient data members to remain in memory within separate containers and written to different folder locations in the output file.

Once data has been loaded from the file and converted from the persistent ROOT streamable type to the transient type, all of the transient containers are connected to the registered modules by passing the addresses of the containers owned by NiffteReconstructor to them so that they may either act on the data stored in the container or fill the container with newly created objects.

After all registered modules have been processed, the reconstructor checks the file extension of the output file and determines whether to write ASCII or ROOT data. In the case of ASCII output, only raw digits are currently written. In the case of ROOT output, all objects in non-empty transient data containers are converted to persistent data objects and written to the appropriate folders in the ROOT output file before the file is closed and job execution ends.

**Documentation**

Doxygen formatted documentation continues to be added and improved. The file \$NIFFTE\offline\doc\README provides the new user with the latest information on getting started running the offline software.

**Hardware/Infrastructure**

Automatic nightly backups of the /home directories on nuclear.calpoly.edu were implemented. These backups archive to the HPSS mass storage system and Livermore. As new user accounts were created on nuclear.calpoly.edu for software development activities, these backups ensure that minimal loss of output would occur in the event of a hardware failure.

The GNU Scientific Library (gsl) 1.11 was installed on the NIFFTE server nuclear.calpoly.edu. For Ubuntu linux distributions, the development packages also need to be installed in order to get the required header files. NIFFTE software assumes that the library is installed in /usr/lib and the header files are in /usr/include. On other systems, if these files are in a different location, the setup scripts and Makefiles for the NIFFTE software may need to be modified.

**Data Acquisition Software [ACU, LLNL]**

This effort will develop all the software required to control the TPC experiment and log the data. An experiment control interface will be developed to allow collaborators to run and monitor the experiment from remote sites, including a slow control system with appropriate interfaces. The front-end cards for the TPC will be quite powerful and flexible because of the Field Programmable Gate Arrays (FPGA). The FPGAs do require programming which we will organize in a framework of modules (each module representing one task) for easy reconfiguration of the device. The modules that would be written for the FPGA would include (1) an ADC receiver that interfaces with the ADC chip, sending and receiving clock signals, receiving the serial data and presenting the data in a pipeline for the next module, (2) preprocessing modules would work with the data before zero suppression, and would include functions such as, ballistic deficit correction, fast proton timing, rebinning, and digital shaping.
**MIDAS Software Evaluation**

The MIDAS software package has been installed on a Linux system at ACU for evaluation purposes. The system uses the Wiener CC-USB CAMAC controller shown in Figure 42. Some software components of interest are an electronic log book (ELOG), web-based run control for remote operation, and ROOT-based online histogramming (ROOTANA and ROODY). Examples of pulse height histograms are shown in Figure 42. The system has been tested locally at ACU and remotely at LLNL. Suitability of the MIDAS package for all or part of the DAQ software for the experiment is presently being considered.

![Figure 42: Examples of the ROOT-based histograms. Shown are pulse heights from 662-keV photons (from a Cesium-137 source) detected by a double-ended plastic scintillator.](image)

**Cooperative Effort for FPGA Programming Optimization**

ACU is involved with an Small Business Innovative Research (SBIR) grant with an Abilene company, Innovation Partners, which involves the design of new ways to program FPGAs and to implement data manipulation in the FPGAs themselves, which will be much faster than doing such things later in software. Innovation Partners is waiting on news of its Phase II proposal after demonstrating in Phase I completed in April, 2008, that one can write code for an FPGA in a matter of hours that can implement many different algorithms. Examples include a software implementation of a Constant Fraction Discriminator to improve timing information from a discriminator by a factor of five or more. Other examples included pulse shaping and writing a Principle Component Analysis pattern recognition program to run in an FPGA. It is hoped that the ACU investigators will be able to leverage this work into improving the performance and capabilities of the FPGA system readout system.

**Slow Controls**

One ACU project this past quarter has been working on the Axiom m5235 Business Card Controller. This uses a Freescale (formerly Motorola) Coldfire mcf5235 microcontroller. This design is being leveraged from the RHIC PHENIX experiment where it will be used as slow controls on at least two different detectors. The board
has several modules that can be used for communication. These are being evaluated as to which is the most appropriate. External communication can be via Ethernet or by building it into a VME crate as a daughter card. This card will permit many different operations, including downloading programs to different DAQ system components, such as FPGA boards.

**Simulation [ACU, GiT, LANL]**

In order completely understand how the TPC will respond to various neutron environments and to accurately determine the fission parameters of uranium and the minor actinides, a complex simulation effort will be undertaken. The environments that the TPC will be used in will require accurate modeling of the detector systems used as well as the neutron production. MCNPX will be used to model the experimental setup at both the LANSCE, the quasi-monoenergetic neutron source at LLNL and Ohio University mono-energetic experimental facilities. These fully detailed four-dimensional models (3D space and time) will be used to create the source term for the GEANT4 modeling of the detector itself. Since MCNPX does not have the ability to transport heavy fission fragments, GEANT has been selected for this task. GEANT only has data for uranium fission events in the G4NDL library and the data for the remaining fissionable isotopes is based on a low precision neutron yield model. GEANT will need to be modified to use the Los Alamos model, also know as the Madland-Nix model, in which fission data will be added for U-238 and Pu-239 and the minor actinides. The modified GEANT module will allow the user to select the Los Alamos model or a fission distribution file supplied by the user. The fission fragmentation model will also be added to this module. To allow for a full model of the detector, another GEANT modification will be the addition of a static electric field modeling capability. This module will be used to accurately model the gas electron amplification inside the detector system. This will allow GEANT to completely model the detection system from birth (through MCNPX) to charge collection in the TPC pads. Using the high fidelity models of the experimental setup facilities, a series of databases will be created for various isotopes. This will allow for rapid comparison with experimental data.

**GEANT4 Sensitive Volume Simulation**

A complete GEANT4 simulation of the TPC sensitive volume has been created and tested. The simulation includes transverse and longitudinal diffusion, digital time latching, charge sharing and pedestal noise. These simulations have been combined with track finding algorithms, which have tested both Hough transforms and Binary Space Partitioning. Both of these methods have been found to be effective in simple event topologies.

Detector response modeling occurs after the transport of the tracks in the GEANT4 is complete. Ion diffusion is physically modeled using edge volumes next to nearest neighbor volumes and sharing some of the deposited charge with that nearest neighbor. The edge volume is relatively small since the maximum diffusion is about 100 µm in this TPC. The diffusion is a z-dependent charge sharing effect and both transverse and longitudinal spreading is incorporated. Even though the impact will be subtle, it has been included to insure the impact is fully appreciated. Also included in the detector response is the TPC interchannel capacitance, a simplified model of which is shown in Figure 43.
Figure 43: This is the simplified TPC inter-channel capacitance model we will use in simulating the detector response. The network will result in some charge sharing between nearest pads.

Figure 44 shows the ionization losses for a 5.0 MeV alpha particle. A SRIM calculation has been included as a reference for the GEANT4 calculation. The complete TPC response has been included in the last calculation. The largest impact on the TPC data at this stage of simulation is the time latching model, which effectively moves the average charge distribution by a half bin, or cell. The full impact of noise and detector response will not be fully revealed until the DAQ system simulation is included.

Figure 44: Shown here are the Bragg curves from three different calculations. The blue points are results of a SRIM calculation. The black line is from a GEANT4 calculation. The red line is the GEANT4 calculation with TPC detector response added but before any zero-suppress algorithms.
Collimator Design

Several milestones were met for the collimator design and the MCNPX model of the LANSCE facility. Continuing the MCNPX version 2.6f computer models, several optimized designs were constructed. A highly detailed model of the LANSCE WNR target/collimator assembly and experiment environment was started. The source neutron energy spectrum was modeled by simulating the interaction of the WNR proton beam incident on the tungsten target assembly. One major milestone that was achieved was the design of a divergent collimator system for the 90L flight path. This design is based on an optical diverging beam profile similar to a pinhole aperture design. A series of stepped cylindrical inserts to the two shutter housings were designed. The inner shutter housing has three apertures for primary collimation. The outer shutter has only one aperture for secondary collimation. Time dependent MCNPX models were run simulating a proton pulse consistent with the pulse time structure at the LANSCE facility. The pulse was defined as a circular beam spot on the tungsten target through the water-cooling jacket, and the stainless steel encapsulation at an 8.25 degree up angle. This assembly is housed in the crypt vacuum chamber. The chamber is inside a large concrete target room whose walls provide the bulk shielding of the source. Several penetrations exist through the bulk shield and serve to create the neutron beams supplied to different experimental areas. A simplified diagram of the target room and associated beam line lines are shown in Figure 45.

![Figure 45: Simplified diagram of the bulk shielding assembly at LANSCE WNR. Beam penetrations are at 15°, 30°, 60°, and 90° on both sides of the beam. The inset shows the 8.25 degree upward angle of the tungsten target to match the proton beam angle.](image)

The effect of room returned and the wall scattered neutrons from inside the crypt were calculated and found to contribute minimally to the neutron spectra exiting the beam penetrations. The calculated lethargy fluence rate exiting the bulk shielding beam penetration at 90 degrees left of the target is compared to the measured fluence rate in in Figure 46. A surface source tally was used at this location to create a neutron source to perform design studies for a custom collimation system for the 90 degree flight path.
Figure 46: The calculated lethargy fluence rate exiting the bulk shield into the 90 degree flightpath with existing collimation is compared with the experimental data. The measurement location was 10.39 meters from the target and used a $^{238}$U fission chamber time-of-flight (TOF) system.

Photographs of the existing collimator/shutter assembly at LANSCE on the 90 degree flight path are shown in Figure 47. Several preliminary designs have been investigated and are being considered. Members of the research team disassembled the shutter assembly and obtained detailed measurements of the inside of the shutter system. In the process, it was discovered the system actually contains three different collimator/filter assemblies available for use.

Figure 47: The shutter assembly exit on the 90 degree flight path. The right picture is a view down the shutter assembly towards the neutron target.
The time profile of the pulse was defined as being Gaussian distributed in time with a 30 picosecond full width at half maximum. A time profile of this can be seen in Figure 48.

![Image](image_url)

**Figure 48:** The time profile of the LANSCE WNR proton pulse, a 30 pS FWHM Gaussian distribution.

The resulting spallation neutrons were transported down the beam line to a tally plane at 10 meters. The resulting beam spots were tallied as a function of two dimensional position as well as a function of energy and time. The beam spots can be seen in Figure A. All of the beam spots produced similarly uniform beams that are similar to each other. For simplicity, only one image of a small beam spot and a large beam spot are shown. If comparing only the spatial profile, all of the designs are nearly identical. It is not until comparing the time-energy resolution of the collimators do we find a clear winner. Several designs are shown below. Following each design, a plot of the time-energy profile is shown. A perfect collimator which follows the time of flight theory when plotting the energy verses time of arrival would produce only a single line with a width corresponding to the proton pulse. However, due to inscatter and room return from the chamber, some designs were better than others. All of the plots look similar to the naked eye until an integral under the peak is performed. A ratio of the neutron fluence rate in the theoretical "line" to the scattered neutron source was performed to provide a metric for comparison. By varying the lead, carbon steel, and borated polyethylene content, as well as including scatter traps (areas for scattered neutrons to be trapped and absorbed as opposed to scattering down the beam line) an optimized design for the large bore diverging collimator was found and shown in Figure 49. Several other designs are also shown in Figure 50, Figure 51, Figure 52, Figure 53, Figure 54, Figure 55 and Figure 56.
Figure 49: Optimal large opening diverging collimator with alternating layers of lead (red), carbon steel (green), and borated polyethylene (pink).

Figure 50: Shown is the time energy distribution of neutrons at the 10 meter experimental station for the optimal large bore collimator assembly. The fluence rate is shown as neutrons per centimeter squared per source proton.
Figure 51: A simple large opening diverging collimator with alternating layers of carbon steel (green), and borated polyethylene (pink). This design produced a rather poor time-energy resolution due to the increased in-scattered neutron contribution.

Figure 52: Shown is the time energy distribution of neutrons at the 10 meter experimental station for a simple large bore collimator assembly of alternating layers of borated poly and carbon steel. The fluence rate is shown as neutrons per centimeter squared per source proton.
Figure 53: Another large opening diverging collimator with alternating layers of lead (red), carbon steel (green), and borated polyethylene (pink).

Figure 54: Shown is the time energy distribution of neutrons at the 10 meter experimental station for another large bore collimator assembly of alternating layers of borated poly and carbon steel. The fluence rate is shown as neutrons per centimeter squared per source proton.
Figure 55: Yet another large opening diverging collimator with alternating layers of lead (red), carbon steel (green), and borated polyethylene (pink).

Figure 56: Shown is the time energy distribution of neutrons at the 10 meter experimental station for another large bore collimator assembly of alternating layers of borated poly and carbon steel and lead with scatter traps. The fluence rate is shown as neutrons per centimeter squared per source proton.

Several small bore designs were investigated. These small bore diverging collimators were designed to produce a one centimeter beam spot at ten meters. The diverging collimator for the small beam spot produced a very uniform beam but at a
significantly lower energy-time deviation. Several plots are shown below accompanied by their schematic layout (Figure 57, Figure 58, Figure 59, Figure 60, Figure 61 and Figure 62). The diverging collimator is suspected of producing such a fine resolution energy-time profiled beam because it only is looking at one specific location on the target, and not the target as a whole.

Figure 57: Optimal small 1 cm opening diverging collimator with alternating layers of lead(red), carbon steel (green), and borated polyethylene (pink).

Figure 58: Shown is the time energy distribution of neutrons at the 10 meter experimental station for the optimal small bore collimator assembly of alternating layers of borated poly and carbon steel and lead with scatter traps. The fluence rate is shown as neutrons per centimeter squared per source proton.
Figure 59: A simple design for the small 1 cm opening diverging collimator with alternating layers of carbon steel (green) and borated polyethylene (pink).

Figure 60: Shown is the time energy distribution of neutrons at the 10 meter experimental station for the a simple small bore collimator assembly of alternating layers of borated poly and carbon steel. The fluence rate is shown as neutrons per centimeter squared per source proton.
Figure 61: A small 1 cm opening diverging collimator with alternating layers of lead (red), carbon steel (green), and borated polyethylene (pink) with additional scatter traps.

Figure 62: Shown is the time energy distribution of neutrons at the 10 meter experimental station for the optimal small bore collimator assembly of alternating layers of borated poly and carbon steel and lead with scatter traps. The fluence rate is shown as neutrons per centimeter squared per source proton.

During the course of this exercise, we have decided to change to a 2.5 cm beam spot for the small design and a larger rectangular profile for the larger profile. A more intense converging collimator is also being designed which will allow for higher fluence rate measurements while still maintaining the small 2.5 cm beam spot. This will be investigated in the first quarter of next year.
The Hydrogen Standard

Scope
The project to accurately and precisely determine fission cross sections hinges on the H(n,n)H total cross section and angular distributions. The H(n,n)H total cross section is well determined with errors less than 0.5%. In the planned TPC measurements, hydrogen will be used as the working gas for a new standards measurement of U-235. The H(n,n)H angular distribution must be known to connect the total cross section to the measured elastic recoils in the TPC.

Highlights
• The hydrogen elastic scattering cross section evaluation has been studied and the differential shortcomings identified. Work continues on the summary of H(n,n)H scattering experiments below 30 MeV.
• Literature survey completed for methods to perform pulse shape discrimination using digital signals. The current methods are very similar to what has been done using analogue signal processing. Several authors expect that this technique will work down to lower energies than analogue signal methods. However, efficiency curves have never been published for a digital signal processing method.
• Improvements in neutron detector technology are being looked at and several new developments hold promise.
• Preparations continue for the upcoming H(n,n)H measurement in early fiscal year 2009.

Hydrogen Standard [OU]
The TPC offers a major advance in technology for measuring the H(n,n)H angular distribution. The solid angle for this detector is a factor of 100 larger than that used in our current measurements at 14.9 MeV. The target thickness would be comparable. This would result in a counting rate increase by a nearly a factor of 100. This may allow high accuracy measurements of the angular distributions. A further factor is that the beam need not be as strongly collimated which would give as much as another factor of 10 statistical improvement. This may reduce the experimental running time for a 1% measurement from 3 months to days. The results would be binned into an angular distribution in the center of mass system. The fitted angular distribution can then be compared to calculations based on potential models such as Bonn or on phase shifts such as Arndt. This may eventually provide a test of the QCD-based model of nuclear forces. We are proposing to collaborate on the modeling of hydrogen scattering in the TPC chamber. We will look at the minimum energy detected. We will also investigate the angular resolution for H(n,n)H scattering in the chamber. A pure hydrogen atmosphere will be investigated along with addition of quenching and/or scintillating gases. Further work will also be done on determining the gas composition and density to better than 0.2%. The systematic errors in a standard measurement must be fully explored in order to reach the desired goal. The modeling work will be focused on these problems. Consideration will also
be given to possible inter-comparison of the neutron standards such as $^6\text{Li}(n,\alpha)^3\text{H}$, $^{10}\text{B}(n,\alpha)^7\text{Li}$ and $^{235}\text{U}(n, f)$.

**Accuracy Improvements**

The first task of this effort was to find ways to improve the accuracy of connecting to the Hydrogen neutron standard. The evaluated total neutron cross section is well determined with an accuracy of at least 0.5 % in the 0.1 to 20 MeV energy range. This is shown in Figure 63. For most nuclear measurements the connection to the total cross section is to measure the proton recoil at one (or more) angles. However, the evaluated angular distribution has been found to differ by over 2% versus angle at 10 MeV over 1% versus energy at 180 degrees (Figure 65).

To resolve these discrepancies two new experiments at 10 and 14.9 MeV have been completed. The results of these two experiments (Figure 66 and Figure 67) show that the measured shape is intermediate to the two evaluations. Errors in the literature were found in the course of the work and have been corrected. The more recent evaluations are now much closer to the values from Arndt and Nijmegan which are based on a phase-shift fit.

A collaboration of Ohio University, NIST and Los Alamos is planning future work to clarify the situation. An inspection of the H(n,n)H angular distribution in Figure 68 shows that a precision measurement of the neutron scattering from 15 to 90 degrees in the center of mass would allow a discrimination between the current phase shift predictions. A measurement of the neutron scattering with an active target is planned. The hydrogen target for neutron scattering will be a scintillator with very good shielding between the neutron source and any area which the detector can see. Initial calculations suggest that this work can be done in less than one month of measurements. The neutron efficiencies will be done relative to the B(d,n) standard spectrum at 7.5 MeV and 60 degrees. Additional measurements will also be done with a well characterized fission chamber (error < 1.6%) from NIST to reduce the error in the B(d,n) standard to better than 2%.

We are working on a summary of all neutron scattering work under 30 MeV. The majority of the references have been collected. The data available from EXFOR at the National Nuclear Data Committee have been downloaded and converted to a common format for plotting and analysis. An initial result is the summary all of the work at “14” MeV shown in Figure 68.
Figure 63: Total Cross Section evaluation plotted with selected experimental results.

Figure 64: Comparison of the predicted differential cross sections at 10 MeV from ENDFB-V and ENDV/B-L.
Figure 65: Comparison of prediction of 180 degree cross section predictions between ENDF/B-V and ENDF/B-VI. iv 

Figure 66: Results of the 10 MeV H(n,n)H Measurement
Figure 67: H(n,n)H Scattering at 14.9 MeV

Figure 68: Summary of all relevant angular distribution measurements at "14" MeV. The relative angular distributions have been arbitrarily normalized to the same 180 degree cross section for comparison.

The summary of the experiments at 14 MeV has been completed. Further analysis is planned to obtain a best value for the angular distribution at this energy. Polarization and scattering data at all other energies have only a few data sets. This will be tabulated in the next quarter. The web sites for the perditions of Arndt, Nijmegan
and Bonn have been used to obtain comparisons with the current summary of the 14 MeV data in Figure 69.

Figure 69: Summary of the "14 MeV" data for neutron proton scattering.

We have had discussions with Charlotte Elster, who has worked extensively with the Bonn Potential, about the status the nuclear force. Currently, the general method of fixing the parameters for the model for the nuclear force is to take a point at the delta resonance and the scattering length. Typically, charge independence is assumed. This gives much stronger weight to the high precision proton scattering.

**Hydrogen measurements**

The new high precision neutron polarization measurement by TUNL has placed new constraints on the nuclear force. They find that a much larger amount of $P_{3/2}$ partial wave is needed than is predicted with the current models. The degree of polarization found in their experiment is much greater than can be produced by current models. Future models of the nuclear force will likely need to include chiral symmetry to account for this degree of polarization and are likely several years off.

We have presented a paper "Towards a precision $^{235}\text{U}/\text{H}(n,n,\text{H})$ Ratio" at the ANS meeting at Anaheim, California. This talk reviewed the status of the present determination of the $\text{H}(n,n)\text{H}$ angular distribution and prospects for improving it in the future.

We are preparing for test measurements in the coming month for $\text{H}(n,n)\text{H}$ scattering. We have ordered 4 detectors as scattering detectors for the test $\text{H}(n,n)\text{H}$ scattering experiment in the end of October. One detector was stilbene, one NE213 equivalent, deuterated benzene and normal benzene. We also have a plastic scintillator detector
and an old stilbene crystal that will be tested. We will use a solid tritium target (titanium tritide on copper or silver) and a 3 cm deuterium cell for neutron production of 14.9 and 10 MeV during this experiment. Most of the work is expected to be setting up shadow shields which block the primary neutrons from the main neutron detector without causing an increase of scattering of neutrons back into the active hydrogen target. The geometry of the experiment is shown in Figure 70. The shadow box and stand are not shown on this diagram. A shadow bar setup has previously been optimized for neutron scattering but not for active target.

![Diagram of the geometry of the neutron scattering experiment.](image)

We are looking at ways to increase the angular range of our measurement for H(n,n)H angular distribution. The correlation between lower energy threshold and angular range is shown in Figure 71. This shows how the lower level detection limit affects the angular range available in the neutron scattering experiment. For a given angle, both the neutron and proton must be detected to be a valid event. For this to be a good measurement, the backgrounds at each energy must also be as low as possible.

![Energy of neutron in the main detector and of the proton in the scattering detector.](image)
The literature survey was completed for methods to perform pulse shape discrimination using digital signals. The current methods are very similar to what has been done using analogue signal processing. Several authors expect that this technique will work down to lower energies than traditional analogue signal processing methods. No efficiency curves have been published for a digital signal processing method.

We are looking at improvements in neutron detector technology. Several new developments hold promise. The best found was $^6$Li-salicylate which should offer good efficiency over a wide range of energies, but the efficiency has never been measured. The best result reported was $^6$Li-salicylate crystals mixed with phenyl-vinyl glue rather than a single crystal or a hot pressed disk. New methods of fabricating trans-stilbene via hot pressing were developed at Sandia. Two papers have recently been published on p-terphenyl as a possible neutron detector. Oak Ridge has a group of nanophysicists who have developed methods on including lithium to a silicon gel.

We have also begun the investigation of other methods of using lithium salicylate in a detector. We have pressed disks of lithium salicylate powder at room temperature and at temperatures up to 320 degree Centigrade. All disks to date have been opaque. At temperatures above 200 degrees Centigrade crystalline structures can be observed following compression. We are currently recrystallizing lithium salicylate from ethanol and methanol and a toluene/alcohol mixture to improve the clarity of the final test detector. None of these new detectors has a published efficiency curve.

We have contacted Natalia Zaitseva at an expert at growing crystals at LLNL about her work on detectors made from salicylic acid derivatives. We have an agreement to test a large single crystal of lithium salicylate.

**Facilities and Operation**

**Scope**

Due to the necessity to have a finely tuned neutron beam, with as little contamination as possible, the experimental area needs to be groomed for TPC installation and running. This will mean additional collimation will be needed to adjust the 90L flight path to work with the TPC. MCNPX simulations will be made of the 90L flight path. In previous work [11] Dr. Hertel and his students have successfully modeled the LANSCE neutron beam. Here he will integrate the help of his graduate students as well as his undergraduate class in the modeling effort. An optimization project in the undergraduate class "Radiation Sources and Applications" will be introduced to encourage undergraduate participation in these high caliber projects. The collimation system will be manufactured at the Georgia Tech Research Institute (GTRI) machine shop. This world class machining facility is available to machine items up to 10m x 10m in size. GTRI employs a large number of undergraduate and graduate students to provide designing and drafting capabilities.

The TPC mount will need to be fabricated. The TPC mount will consist of a 3-axis positioner that the TPC will mount to that will allow for precise positioning of the TPC in the neutron beam. The design specifications will come from the TPC design team,
as well as 3 axis movement specifications for fine tuning in the LANSCE beam. The mount will be designed at Georgia Tech and machined at GTRI to match the exact specifications provided by the design team. Student participation will be fostered by introducing the problem into a joint nuclear engineering and mechanical engineering student senior design project. The experimental infrastructure will be partially provided by facilities currently at the LANSCE facility. Georgia Tech graduate and undergraduate students will participate in the scoping and design of the experimental facilities that will house the TPC at LANSCE. A good working rapport will be established with the facilities personnel at LANSCE through this collaborative effort.

The TPC experiment will be maintained and monitored while located at LANSCE. The Nuclear Science group employs a number of qualified technicians who will perform the required upkeep and maintenance of the TPC and related systems. The facilities will be maintained to that the instrument will function properly and beams can be supplied to the area. The TPC detector and associated electronics will be maintained as necessary. The gas system will be monitored and maintained, including gas bottle replacements and any required periodic testing. The data acquisition system will be maintained by experimenters and a LANSCE supplied computer technician.

In addition to running at LANSCE, the TPC will also run at other facilities to cross check systematic errors. This will be critical to achieve the small systematic errors that are the goal of this experiment. One possibility is the ALEXIS facility under construction at LLNL. This mono energetic neutron source is notable for the low cost ($150/hr to have the whole facility) and high luminosity \(10^8\) n/s at 10 cm) neutron beam that will complement the LANSCE facility.

Another notable resource is the accelerator at Ohio University, which will be used to study the hydrogen standard for this project and develop the data required to extend the small uncertainties in the \((H(n,n)H)\) total cross section to the actinide measurements.

**Highlights**

- ALEXIS accelerator at LLNL will be operation for TPC testing in FY09.
- LANL TPC safety briefings have brought in a number of safety subject matter experts to insure smooth operation of the experiment at LANSCE.
- Permits have been obtained at Edwards Accelerator for TPC testing.
- The TPC building at LANSCE received new interior paint on walls, floor and shielding blocks.
- New storage containers have been ordered for the experimental area to house the TPC supporting equipment.
- Pulse stacked beams were delivered for the first time ever at the WNR at LANSCE in a test of this particular mode of running which provides the world’s highest flux over the entire fast energy region with spectroscopic quality structure.
Livermore [LLNL]

There are numerous facilities at LLNL that are of interest to this project. The biggest is the construction of ALEXIS, Accelerator at Livermore for EXperiments in Isotope Sciences, scheduled for operation in FY09. This facility will generate pseudo-monoenergetic neutrons up to $10^8 n/s/cm^2$ at energies from 100keV up to 14MeV at low operating cost. The LC computing system has large CPU clusters and storage systems that have been successfully utilized by similar computing projects such as Phenix at RHIC, MIPP at FNAL, and is currently working on setting up ALICE at CERN.

Los Alamos [LANL]

The Nuclear Science group at Los Alamos Neutron Science Center operates and maintains the Weapons Neutron Research facility that provides spallation neutrons to five flight paths. The group also maintains and operates two moderated neutron flight paths in the Lujan Center. The group operates and maintains the Blue Room facility, with access to an 800 MeV proton beam and a Lead Slowing Down Spectrometer. The Nuclear Science team will provide the floor space and neutron beam access to the TPC project primarily on the 90Left flight path at the WNR and flight path 5 of the Lujan Center. The 90L flight path experimental area is inside a new construction that contains an overhead crane, light lab space, a vented hood, source safes, computers and easy access to the neutron beam line. Flight path 5 experimental area includes an overhead crane, light lab space, source safes, computers and easy access to the neutron beam line. Recently refurbished light lab space will also be available for TPC work. Monitored stacks are in the vicinity of the two flight paths for TPC gas system and hood exhausts. Radiological shipments and handling facilities are also available. The LANSCE facility provides outside users with all necessary training, a cafeteria and meeting rooms.

Preliminary Safety Briefings Conducted

Safety subject matter experts were engaged on many of the specifics of the TPC experiment at the LANSCE facility. Operation of the TPC experiment at the WNR will require a safety basis authorization for all the unlisted and unapproved electronics, the hydrogen gas system including krypton calibration system, the actinide inventory control, filtering and venting requirements, mechanical loads of collimator systems, shutter removal and modifications, and personnel protective systems.

Health physicists were included in the briefings that explain the experimental challenges of the measurements, which will require open-faced actinide targets on thin backings with little to no contamination mitigation. The TPC targets will also need to be changed on a regular basis and thus requires a work permit and process for handling these delicate targets outside a glove box. The TPC and supporting facilities will be designed to minimize the impact of an accidental actinide release.

WNR pulse stacking tests were completed

Neutron beams were generated at the WNR facility for the first time using protons from the LANSCE accelerator that were stacked in the Proton Storage Ring before being delivered to the WNR spallation target. Standard parallel plate ionization
chambers were used to collect fission data for U-235, U-238, Np-237 and Pu-239 to determine the timing resolution in this configuration from thermal energies to 20 MeV.

The GNEP program requires high accuracy nuclear data in a very challenging energy region for use in modeling, simulation and design efforts for the future fuel cycle. The nuclear data requirements and priorities are determined by the sensitivity studies performed as part of the national program. The specific reactor data needs include fission and capture cross section measurements as well as fission outputs and yields. It is also foreseen that the GNEP program will requires high sensitivity techniques to address non-proliferation concerns as well as criticality safety.

The LANSCE facility provides neutron sources that extend from sub-thermal energies to several hundred MeV. The Lujan and the WNR sources provide 12 decades in incident neutron energy reach. Recent results (cite papers) have shown the power of the LANSCE facilities for fast reactor applications. High reactor flux in the fast region requires unprecedented precision in the nuclear data in that region to minimize uncertainties in the calculated reactor integral parameters. The fast region is a challenging energy region and although it can be reached at LANSCE, the heart of the fast flux spectrum is in a region of overlap between the two facilities and results in relatively largest systematic uncertainties. Pulse stacking at the WNR would resolve this issue by providing a single facility that covers the entire energy range of interest to fast flux applications.

The pulse stacked beams at the WNR will also provide a minimum factor of 5 increase in the neutron flux by utilizing proton pulses that are currently rejected in order to meet energy reach requirements. Compared to Lujan, the pulse stacked beams at the WNR will provide a factor of 1000 in neutron flux in the fast region. The increase in luminosity will not only help minimize any time-dependent systematic uncertainties but allow access to measurements on highly radioactive samples, which can then be reduced by many factors due to the increased flux. Precision kinematic fission measurements will also be improved due the ability to use even thinner samples for experiments.

The WNR time structure will also be advantageous to making precision measurements in the resonance region, where safeguards and criticality safety will benefit greatly. Pulse staked beams at the WNR will provide unprecedented resolution and neutron flux for these hard to make measurements into the 10's of keV region.

Figure 72 shows a plot of the Lujan and WNR neutron flux, along with the pulse stacking expectation. The increase in WNR flux is due to a more efficient use of protons from the linac. Nominal WNR running requires 80% of the proton pulses be rejected to insure enough time between pulses to reach energies as low as 100 keV. Pulse stacking will allow the use of these protons and increase the WNR luminosity by a factor of 5. The stacked pulses will be delivered in such a way as to guarantee the necessary low energy reach, and in a much more flexible manner.
Figure 72: Shown here is the Lujan (green) and WNR (blue) neutron flux shapes as a function of neutron energy. The WNR low-energy reach can be extended to lower energies by removing protons incident on the spallation target, reducing the available flux. The pulse stacking (red) flux represents an increase of a factor of 5 over WNR by utilizing proton pulses that are thrown away for nominal energy reach and represents a factor of 1000 over Lujan flux at 100 keV.

The LANSCE proton storage ring pulse stacking upgrade consists of three major elements, shown in Figure 73. An RF buncher is required to keep the circulating protons from spreading due to mutual repulsion. A fast extraction kicker will be needed to eject the circulating proton pulse. The kicker will be designed to insure that it will be compatible with stacking more than one pulse in the ring at one time. A switching magnet will also need to installed, along with matched transport, to allow simultaneous operation of the WNR and the Lujan center.

Figure 73: Shown here is a diagram of the required LANSCE proton storage ring upgrades required to deliver pulse stacked beams to the WNR in an acceptable production mode.
The existing PSR was operated in a novel way to produce short but intense bursts of protons every 25 milliseconds, much like one on the pulse stacking modes envisioned. The technique exploited the periodic motion of the protons in longitudinal phase space to insure a very narrow, intense pulse. Only a fraction of the available charge could be used in this test but was already enough that new current limiting devices had to be installed to avoid accidental, high radiation spills. The average current during this test was very similar to the nominal WNR current, except it arrived in “super” pulses.

Traditional fission measurements were carried out at 90L to get a first glimpse of the data from this mode of operation. We realized within minutes that these large pulses could wreak havoc on much of the electronics developed for standard running and nearly a day was spent implementing creative solutions. Figure 74 shows a fit to the gamma ray induced fission events in our detector. The time response is a convolution of many sources, most of them less than a few hundred picoseconds. Most of the width measured is due to the physical extent of the spallation target and the proton pulse width. The fitted width suggests that the proton pulse width was less than 1.5 nanoseconds and proves that the stacking technique was successful.

![Figure 74: Shown here is the best fit to the gamma induced fission events taken on 90L during the pulse stacking tests. Gamma rays from the spallation process arrive at the detector location first, well separated from the later arriving neutrons. A fit to these data reveal the timing resolution of the entire system, including the proton pulse width, which is limited to be less than 1.5 ns.]

Fission data were collected using high speed digitizers to insure the best resolution possible. Figure 75 show low energy U-235 fission data taken during the test. The narrow proton pulse width is well below what is required for spectroscopy in this region. However, the data taken in this energy region confirm that the pulse stacked beams deliver useable data well below the fast region.
Figure 75: Shown here are raw fission data (red) and the ENDF evaluation (blue) in the low energy region. It is clear from this plot that the WNR pulse stacked data reached to energies well below the fast region. These data were collected in about 8 hours of running.

The resonance region resolution is dominated by the proton pulse width and the physical extent of the spallation target. Figure 76 shows that after only 8 hours or so of data taking, it is clear that the pulse stacked WNR beams will be able to deliver spectroscopic quality data in the resonance region. The level of backgrounds in this test were relatively high and no attempt to shield or subtract these data were made in these plots. A fully developed experimental area will remove these unwanted contributions entirely.
Figure 76: Shown here are raw fission data (red) and the ENDF evaluation (blue) in the resonance region. It is clear from this plot that resonance measurements will be possible with pulse stacked WNR beams. These data were collected in about 8 hours of running.

90L Experimental Support

Extra storage facilities have been authorized to support experimental activities on the 90L flight path. New transportainers will be situated near the experimental to store the variety of experimental support equipment for this and other projects.

The TPC alignment laser was delivered, along with the harmonic generator required to deliver the 266 nm beams to the TPC. Local LANL laser support has been identified to assist in implementing the TPC, not only to the TPC itself, but into experimental area as well, to insure all safety and operational conditions are satisfied.

Ohio University [OU]

The work proposed will be undertaken in the Edwards Accelerator Laboratory of the Department of Physics and Astronomy at Ohio University. The laboratory includes a vault for the accelerator, two target rooms, a control room, a thin film preparation and chemistry room with a fume hood, an electronics shop, a teaching laboratory for small non-accelerator based nuclear experiments, and offices for students, staff, and faculty. The Laboratory building supplies approximately 10,000 square feet of lab space and 5,000 square feet of office space. In the Clippinger Research Laboratories,
The Department of Physics and Astronomy has a 3000 square foot mechanical shop, staffed by two machinists, that supports all the experimental work of the department. The machinists have numerically controlled machines that they use in the fabrication of apparatus used in experiments, they are accomplished at making parts from exotic materials such as refractory metals, and can perform heli-arc welding and other sophisticated joining techniques.

The heart of the Edwards Accelerator Laboratory is the 4.5-MV tandem Van de Graaff accelerator and six beam lines. This machine is equipped with a sputter ion source and a duo-plasmatron charge-exchange ion source for the production of proton, deuteron, 3,4He, and heavy ion beams. DC beams of up to 30 µA are routinely available for protons, deuterons and many other species from the sputter ion source. Pulsing and bunching equipment are capable of achieving 1 ns bursts for proton and deuteron beams, 2.5 ns bursts for 3,4He beams, and 3 ns bursts for 7Li. The accelerator belt was replaced most recently in March 2004; the accelerator has performed very well since that time with good stability for terminal voltages up to 4.0 MV. The SF6 compressor and gas-handling system were refurbished in April 2005. The Laboratory is very well equipped for neutron time-of-flight experiments. The building is very well shielded thus allowing the production of neutrons from reactions such as d(d,n). A beam swinger magnet and time-of-flight tunnel allow flight paths ranging from 4 to 30 m. The tunnel is well shielded, and the swinger-magnet assembly allows angular distributions to be measured with a single flight path.

Management

The NIFFTE university collaborators are funded under a NERI-c contract. The PI of this contract has reporting responsibilities for that grant. The laboratories are being funded directly through the GNEP Reactor R&D campaign to not only participate but to provide guidance and project oversight, including reporting requirements within the GNEP management system.

Work Breakdown Structure

A Work Breakdown Structure (WBS) is being developed by LLNL and LANL to detail the scope of effort required to meet all milestones. Progress is updated on the collaboration wiki pages where it is also used as the outline for online documentation and progress updates.

Collaboration Meetings Conducted

The first general meeting of the NIFFTE Collaboration was hosted by Abilene Christian University at the ACU Conference Center near the Dallas-Fort Worth Airport on 19 January 2008. The site was chosen for the convenience of meeting near a major airport. A photograph and list of the attendees is included in Figure 77.
Figure 77: Participants of the first NIFITE collaboration meeting held at the ACU Conference Center near the DFW airport. Back row: Joseph Kish (ACU), Mike Heffner (LLNL), Uwe Greife (Colorado School of Mines), and Nolan Hertel (Georgia Institute of Technology). Front row: Rusty Towell (ACU), Mike Sadler (ACU), Tony Hill (LANL), Lucas Snyder (CSM), Eric Burgett (GIT), Tom Massey (Ohio U.), and Donald Isenhower (ACU). Not shown (taking the picture) is Shon Watson (ACU). Participating remotely was Jenn Klay (CalPoly).

A second NIFITE collaboration meeting was conducted at the American Nuclear Society meeting held in Anaheim in Jun 2008. This meeting was called because a quorum could be convened without added expense. A photograph, including the list of attendees is included in Figure 78.

Figure 78: Participants of the second NIFITE collaboration meeting held at Disneyland in Anaheim, CA. Participants included, from left to right (front row), Eric Burgett (GIT), Fredrik Tovesson (LANL), Jenn Klay (CalPoly), Mike Heffner (LLNL), Tom Massey (OU), Nolan Hertel (GIT) and (back row) Tony Hill (LANL), who took the picture and photoshopped himself in as the big rat.
References

iii Zhou, JACS, 121, 9712 (1999).
viii Ch. Duellmann, private communication, 2007.