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Quarterly Technical Report, Fission Time Projection Chamber Project, April2012

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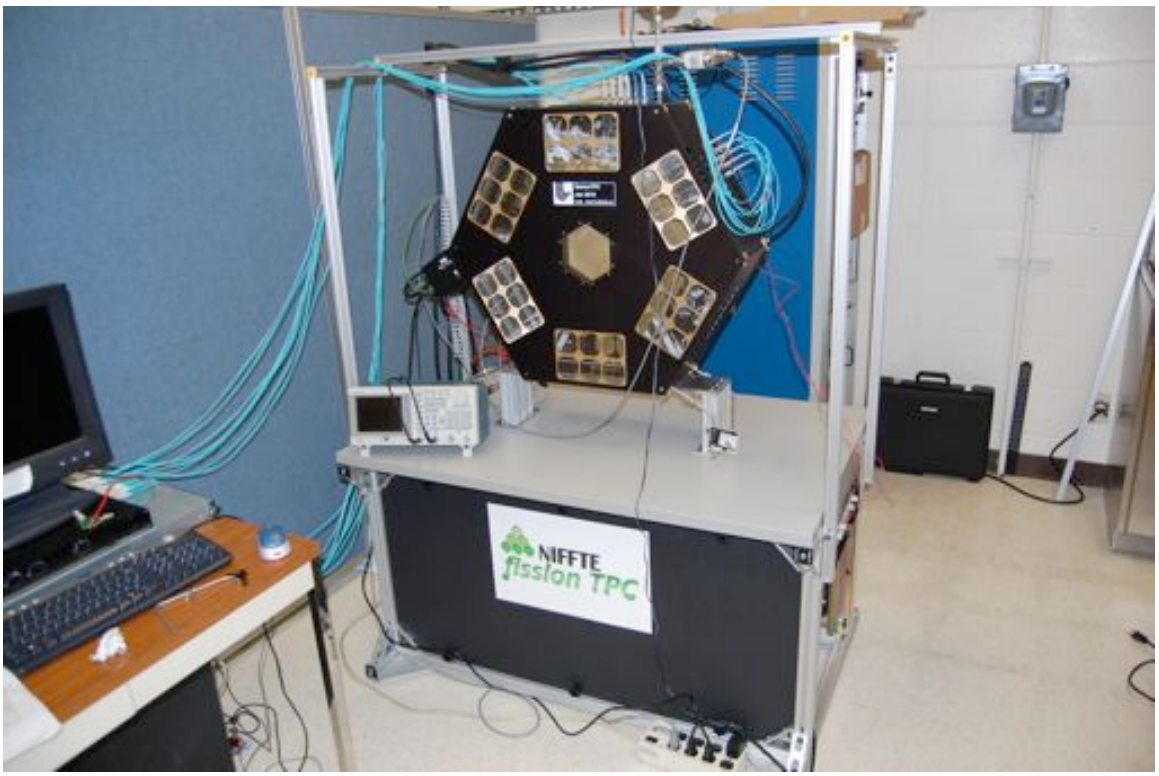
U.S. DEPARTMENT OF ENERGY

April 2012

Quarterly Technical Report
Fission Time Projection Chamber Project

Collaborative Research Initiative



The Time Projection Chamber is a collaborative effort to implement an innovative approach and deliver unprecedented fission measurements to DOE programs. This 4π-detector system will provide unrivaled 3-D data about the fission process. Shown here is the TPC with a fully instrumented sextant at the LLNL TPC laboratory.

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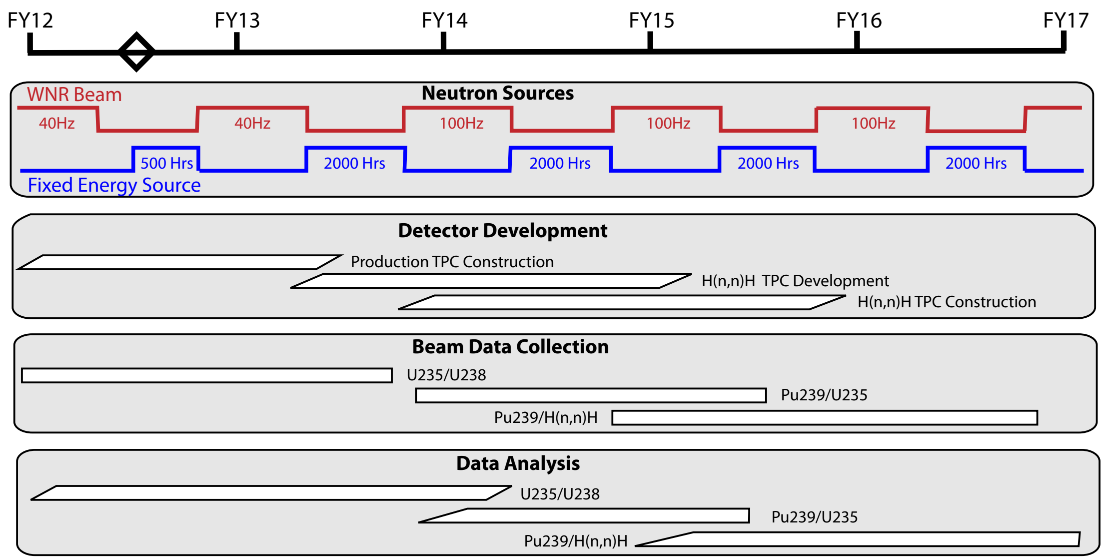
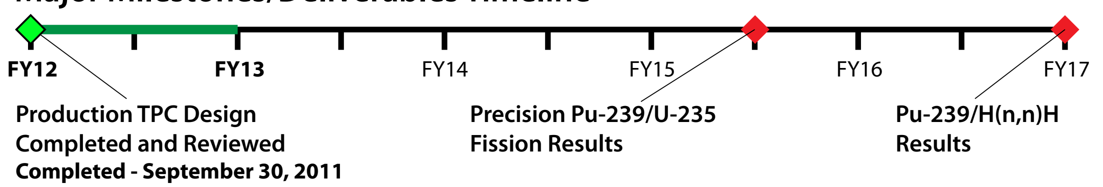
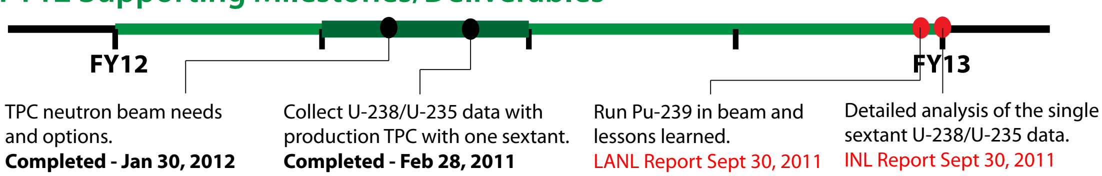
TPC Project Timeline



Major Milestones/Deliverables Timeline



FY12 Supporting Milestones/Deliverables



Second Quarter Highlights FY12

- The latest TPC hardware was operated on the 90L flight path. LANSCE beams were stable and high quality data from U-235/U-238 and Pu-239 targets were collected using a full sextant.
- TPC neutron beam needs and options were identified and documented.
- Significant progress has been made to scale up the upcoming experiments to a half-instrumented TPC.

Potential Timeline Issues and Concerns

- Reductions in funding have pushed the major milestones beyond FY13 out by a year with further delays possible without restored funding.
- 100 Hz operations at the LANSCE accelerator have not been recovered yet and the schedule is unclear.
- The facility for fixed neutron energy measurements has not been identified but work is underway to provide a comprehensive overview. The level of effort for this will be increased in the upcoming months.

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Acronyms and Symbols

ACU	Abilene Christian University
AFCI	Advanced Fuel Cycle Initiative
AFM	Atomic Force Microscopy
Am	Americium
ANL	Argonne National Laboratory
ANS	American Nuclear Society
ASME	American Society of Mechanical Engineers
Atm	Atmosphere (pressure unit)
Ba	Barium
Be	Beryllium
Bi	Bismuth
BNL	Brookhaven National Laboratory
CalPoly	California Polytechnic State University, San Luis Obispo
Ce	Cerium
Cm	Curium
CS	cross section
Cs	Cesium
CSM	Colorado School of Mines
Cu	Copper
CVD	Chemical Vapor Deposition
DANCE	Detector for Advanced Neutron Capture Experiment
DAQ	Data Acquisition System
DOE	Department of Energy
dpa	Displacements per Atom
EIS	Environmental Impact Statement
ENDF	Evaluated Nuclear Data File - Evaluations that can be used in MCNPX for more accurate predictions of fission, criticality, transport, and radiation damage
ES&H	Environmental, Safety, and Health
Eu	Europium
Fe	Iron
FPGA	Field-programmable gate array
FWHM	Full Width Half Maximum
GEANT4	Geometry And Tracking monte carlo program from CERN
GIT	Georgia Institute of Technology
GNASH	Nuclear Reaction Code
H	Hydrogen
He	Helium
HEU	Highly enriched uranium
Hf	Hafnium
Hg	Mercury
IAC	Idaho Accelerator Center
IAEA	International Atomic Energy Association (Vienna, Austria)
IFR	Integral Fast Reactor
INL	Idaho National Laboratory
ISTC	International Science and Technology Centre (Moscow)
ITU	Institute for Transuranium Elements (Karlsruhe, Germany)
JAERI	Japan Atomic Energy Research Institute
JLAB	Jefferson Laboratory (VA)
K	Potassium
keV	Kiloelectron Volt
Kr	Krypton

LA150n	Los Alamos generated nuclear data library, extending up to 150 MeV
LAHET	Los Alamos High-Energy Transport
LANL	Los Alamos National Laboratory
LANSCE	Los Alamos Neutron Science Center
LLFP	Long Lived Fission Products
LLNL	Lawrence Livermore National Laboratory
MA	Minor actinide
mb	Millibarn
mCi	Millicurie
mips	Minimum ionizing particles
MCNP	Monte Carlo N-Particle Transport Code
MCNPX	Merged code—Los Alamos High-Energy Transport (LAHET) and Monte Carlo N-Particle Codes (MCNP)
mL	Milliliter
Mo	Molybdenum
MOX	Mixed-oxide fuel
mR	Millirad (a measure of radiation)
N	Nickel or nitride
Np	Neptunium
NEA	Nuclear Energy Agency (Paris)
NEPA	National Environmental Protection Agency
NERAC	Nuclear Energy Research Advisory Committee
NERI	Nuclear Energy Research Initiative
NIFFTE	Neutron Induced Fission Fragment Tracking Experiment (TPC Collaboration name)
O	Oxygen or Oxide
O&M	Operations and Maintenance
ORNL	Oak Ridge National Laboratory
OSU	Oregon State University
OU	The Ohio University
PACS	Personnel Access Control System
Pb	Lead
Pd	Paladium
PNNL	Pacific Northwest National Laboratory
Pu	Plutonium
PUREX	Plutonium-Uranium Extraction
QA	Quality Assurance
R	Rad (a measure of radiation)
rms	root mean square
ROOT	an object oriented data analysis framework from CERN
RSICC	Radiation Safety Information Computational Center
Ru	Ruthenium
SEM	Scanning Electron Microscopy
SNF	Spent Nuclear Fuel
SNL	Sandia National Laboratory
SRS	Savannah River Site
STP	Standard Temperature and Pressure
Ta	Tantalum
Tc	Technitium
TEM	Transmission Electron Microscopy
TJNAF	Thomas Jefferson National Accelerator Facility
TPC	Time Projection Chamber
TRL	Technical Readiness Level
TRU	Transuranics (americium, curium, neptunium, and plutonium)
TRUEX	Aqueous solvent extraction process for TRU recovery

U	Uranium
UREX	Uranium Extraction (an aqueous partitioning process)
V	Vanadium
W	Tungsten
WBS	Work Breakdown Structure
WNR	Weapons Neutron Research (facility at LANSCE)
Xe	Xenon
Y	Yttrium
Zr	Zirconium

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Time Projection Chamber Project

Introduction

Reactors, weapons and nucelosynthesis calculations are all dependent on nuclear physics for cross sections and particle kinematics. These applications are very sensitive to the nuclear physics in the fast neutron energy region and therefore have large overlaps in nuclear data needs. High performance computer 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 calculated performance parameters. The impact of nuclear data uncertainties has been studied in detail for reactor and weapon 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 DOE programs and the TPC measurement program will help provide those data. The result of these new, high-accuracy precision measurements will be a refined understanding of performance results, thus reducing the liability nuclear data has on the overall uncertainties in calculated integral quantities. The new class of high-accuracy, high-precision fission measurements will not be easy. The proposed method is to employ a Time Projection Chamber and perform fission measurements relative to 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 that 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 theTPC 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 and accuracy 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}U/n(n,p)p. The ^{235}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 DOE nuclear 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 [LLNL, CSM, INL, ISU, ACU]

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

- The latest version of the pad plane was completed and several have been constructed.
- A production run of 30 digital bus boards was completed this quarter, and a full testing procedure has been developed.
- A production run of 80 EtherDAq board was completed this quarter and testing is underway. These cards, along with the previous ones, will be used to instrument the TPC to the 50% level in the upcoming LANSCE beam cycle,
- A new HV system for the delicate micromegas has been developed that can be controlled by computer for remote operation and has the required sensitivity for very low trip limits. A record of invention was filed with the LLNL patent office for the novel solution.

- A suite of targets have been fabricated for performance testing of the TPC before shipping to LANL.

Time Projection Chamber [LLNL, CSM, INL]

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

Cathode Pad plane

The next version of the pad plane (version 3) was designed and built in this quarter. This version has improvements to the glue down region for the micromesh and more importantly is setup for robotic placement of the 96 connectors that go on each board. With fully loaded connectors, we will have the option of instrumenting any sector as needed. 12 boards were built and received at LLNL. They were inspected for correct pillar height and some other preliminary inspections, and then sent to the loading shop for connector placement.

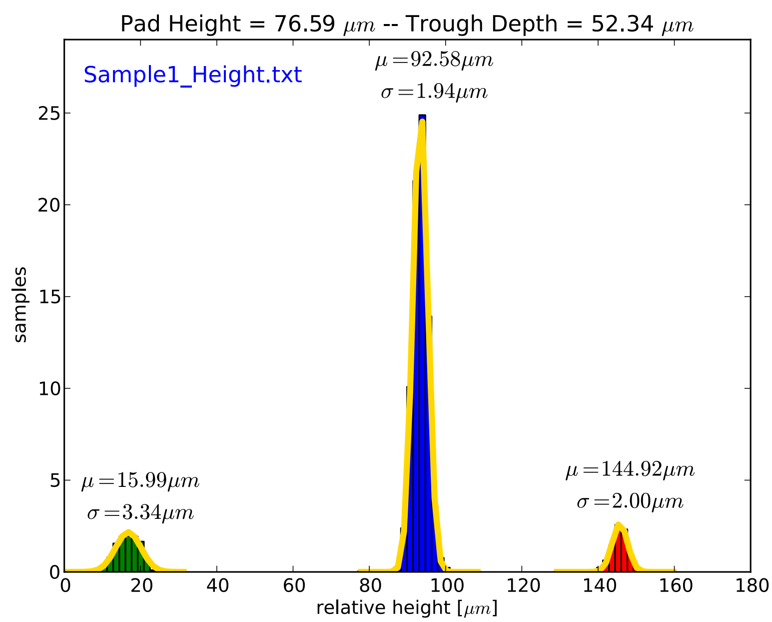

Figure 1: Shown here is the pad plane profilometry measurement summary revealing the consistency of construction.

Laser Alignment System

The laser calibration system for the TPC is important to measure field distortions caused by positive ions in the drift gas. The first design was to use a fiber to transport the laser beam from the laser head to the pressure vessel and down optical rods with prisms at the ends. After a number of attempts to use a fiber we found that it simply can not handle the power. We have decided to change the design to match closer to a proven design used in the STAR TPC experiment. A conceptual design of the TPC laser system has been completed, and work has started on the details of constructing that design. The first difficult problem is mounting and carefully aligning the very small (1mm) and fragile glass rods. It was determined that a small flat ground into the glass could be used with a fixture to align the rods and then epoxy them in place. The alignment fixture has been designed, and the next step is to test this procedure.

Data Acquisition System [LLNL, ACU, ISU, INL]

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.

Preamplifier Cards

It was observed at LANSCE that the micromegas was not as stable as the operations at LLNL. The discharges happen every few days or so, and each time the discharge hits a preamp it kills the preamp fet (~$1 part) that is difficult to replace in the field. We think the discharges are the result of dust entering the TPC and the environment at LLNL is substantially cleaner than at LANSCE. We are working to clean up the work area at LANSCE and also working to make the preamps more robust against sparking. A prototype for the protection circuit was designed and tested. It was tested both for the ability to withstand sparks, and that is does not increase the noise of the system. The PCB was modified and is ready for production. We don't currently have the funds to make this run so we are holding off for now. We will use the older unprotected preamps for the next run cycle.

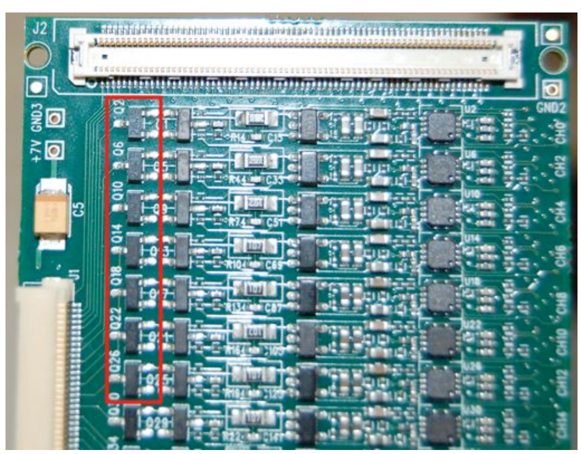

Figure 2: The FETs that are damaged by sparking in the TPC.

EtherDAQ Cards

A production run of 80 EtherDAq board was also completed this quarter. These board will be tested this summer for the next run cycle at LANL and for 252Cf runs at LLNL.

The EtherDAQ firmware has been improved to handle long pulses better. The grounding is very noisy at LANL and we have taking great care in isolating the ground of the TPC from the power ground at LANL. One issue is the need to have some signals cross (electrically) the barrier between these two grounds. We have tested an optical bit-driver that appears to have the speed to transport the signals and since it is optically transmitted, it does not cause any problems connecting grounds.

High Voltage System

A new HV system for the delicate micromegas has been developed that can be controlled by computer for remote operation and has very sensitive trip limits. It was placed on the TPC at LANCSE and appears to work well. One issue discovered was that the batteries are drained too quickly (3 days). We designed a fix to this that allows it to run off a power supply, but not increase the noise. The solution was to use a solar cell and leds to power the HV (5kV). This worked so well that a record of invention was filed with the LLNL patent office. The first one sent to LANL was a prototype. We have since made a better version with custom printed circuit boards that should be even more robust and tested that at LLNL. We will also update the unit at LANL for the next run.

Figure 3: New high voltage system for the micromegas.

HiSCaR

The cathode of the TPC can be instrumented to determine the time-of-flight of neutrons arriving at the TPC. This is used to determine the energy of the neutrons to make the cross section measurement. This system consists of two parts. The first is an analog amplifier that takes the small signal from the cathode, amplifies it and conditions it for recording by a digital system. This amplifier has to be fast and low noise which is difficult to accomplish simultaneously. A first version of this amplifier has been built and we are working to refine it. The second part is the digital readout. This is complicated by the fact that we need the timing with respect to the master TPC clock. We have solved this by using a TPC card and making a special interface card that takes the signal from the preamp and delays it 20 times each for just 1 ns. The delayed signals are fed into 20 channels and from this we can get very good timing. This part has been tested with a pulser and works well. This quarter we have integrated the two parts and we now have a higher speed readout of fission at the cathode. This was done at LLNL with a 252Cf source. The rise time is limited by the cable capacitance at the front end and is currently 300-400ns. This is too long, but will be used to get started in the next run cycle. Working with a pulser, it looks like 10-20ns rise is possible once the amplifier is placed inside the TPC; something we plan to have by at least the run cycle in CY13.

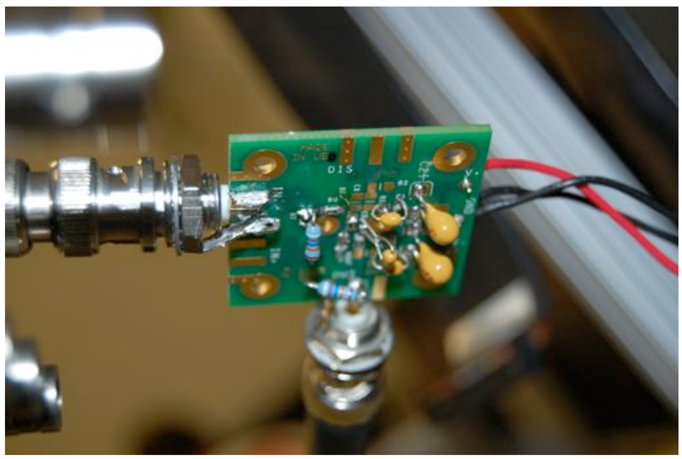

Figure 4: Prototype preamp used on the TPC cathode.

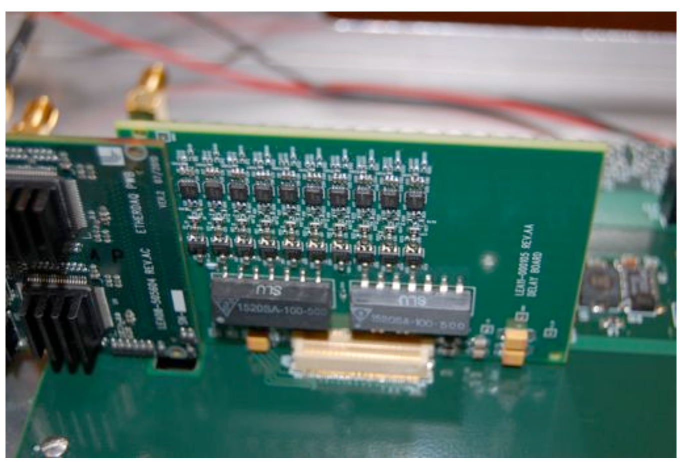

Figure 5: Delay board used to get high speed timing with the TPC electronics need to get the signal readout on the TPC timebase.

Power and Clock Distribution

The power and clock distribution system (PCDU) was completed for 2 channels and deployed at LANSCE. This allows for operation of 32 front end cards, and is a demonstration of what is needed to power the whole TPC. Simply scaling up this box will provide the approximately 4kW of power needed. It also has feature such as a remote shutoff and status for remote operation. We have also populated a full chassis at llnl and tested the system. It has been discovered that the system was unstable when some signals were plugged into the PCDU. Specifically when the trigger hold-off was connected, the cards would send corrupted packets. We traced this down to a grounding problem in the chassis and have fix it. We have tested the system with a range of signals and over a day to make sure it is stable. We will upgrade the LANL box with this fix and also finish populating all channels. In the process we also found a bad termination in the JTAG on the digital bus board. This is a very easy fix to simply remove one resistor and change the value of another.

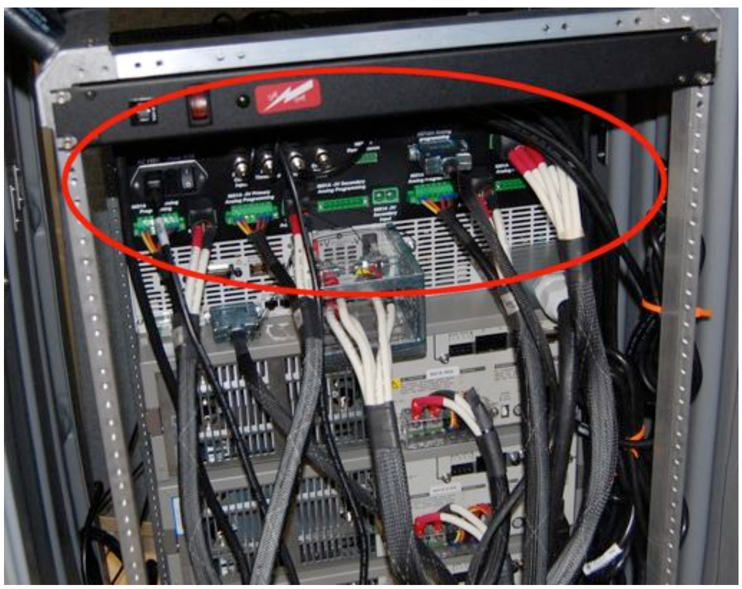

Figure 6: The power and clock distribution system.

Digital Bus Board

A production run of 30 digital bus boards was completed this quarter, and a full testing procedure has been developed. The boards will be tested this summer for the next run cycle.

Preamp Test Stand

Significant progress has been made on the preamp test stand installed in the Advanced Electronics clean room at the ISU RISE complex (see Figure 7). Functionality has been added to the EtherDAQ GUI to control the pulse generator, read the data stream from the EtherDAQ card, and produce waveform and analysis ROOT plots from within the GUI. A new waveform analysis model has been written into the analysis routines for performing a running average and mean of waveform parameters. The EtherDAQ GUI will have an XML output file structure that includes all of the test parameters in a heading and all of the collected waveforms for those test parameters. Each preamp card will be assigned a performance grade included in the XML file.

Figure 7. The preamp test stand installed in the Advanced Electronics clean room at the RISE complex at ISU.

The waveform analysis routines have been developed with interactive testing from a nominal preamp and etherDAQ card. Testing has included waveform amplitude and pulse width analysis to determine saturation voltage, voltage linearity (see Figure 8), charge collection as a function of pulse width, and minimum pulse width required for full charge collection. Over the course of the next several months, all of the preamp cards will be tested in anticipation of instrumenting a full TPC.

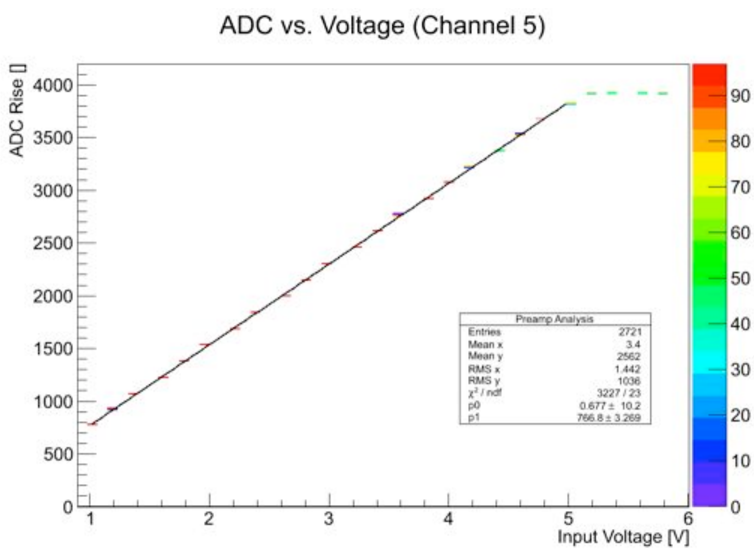

Figure 8. Sample preamp voltage linearity test.

Gas Handling and Temperature Control Systems [CSM, LLNL]

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 $^{1}H(n,n)^{1}H$, 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 gas supply system has been successfully operating during active data collection at the 90L experimental hall at LANL. Some minor issues have been identified and will be addressed in the upcoming quarter. The gas system has exhibited some pressure instability (fluctuations less than 1%) that has been correlated with the temperature in the room and specifically with the air conditioner/heater cycle. Minor adjustments to the PID control system parameters should be able to smooth out most of the fluctuations. Insulating the TPC and the gas system and redirecting the air flow from the air conditioner/heater will also help reduce the fluctuations.

The gas system software is currently controlled by LabVIEW and is installed on a Windows OS. Several times after long periods of operation the gas system control computer restarted and the gas system flow was stopped. It is suspected that these unexpected computer restarts are a result of a minor memory leak in the LabVIEW software or are simply the fault of the operating system. To address these problems, the feasibility of transferring the gas system control to a C++/Linux based system is being investigated. In addition to improving the stability of the gas control system software, a C++ based system will be more easily integrated with the current MIDAS data acquisition software and it will allow the gas system control to be easily and securely accessed remotely. An intermediate step also being pursued is the transfer of the LabVIEW control from a Windows OS to a Linux system.

Electron Lifetime Monitor

The electron life-time monitor measures the drift speed and purity of the gas in the TPC. These parameters are important for the calibration of the TPC. The electron lifetime monitor was tested with P5 gas and electric fields comparable with those currently employed in the TPC. Electron drift at different electric field across ~10 cm was demonstrated by measuring the collected charge at the anode. It was also shown that the light produced by the flash lamp and directed on the photocathode using the fiber optic creates a large number of photoelectrons from the photocathode. The canary was reconfigured with an additional high-voltage power supply and a second charge preamp was connected to the cathode. Tests were performed at different electric fields to preliminary assess the behavior of the device, like grids transparency, electron extraction from photocathode, and charge collection.

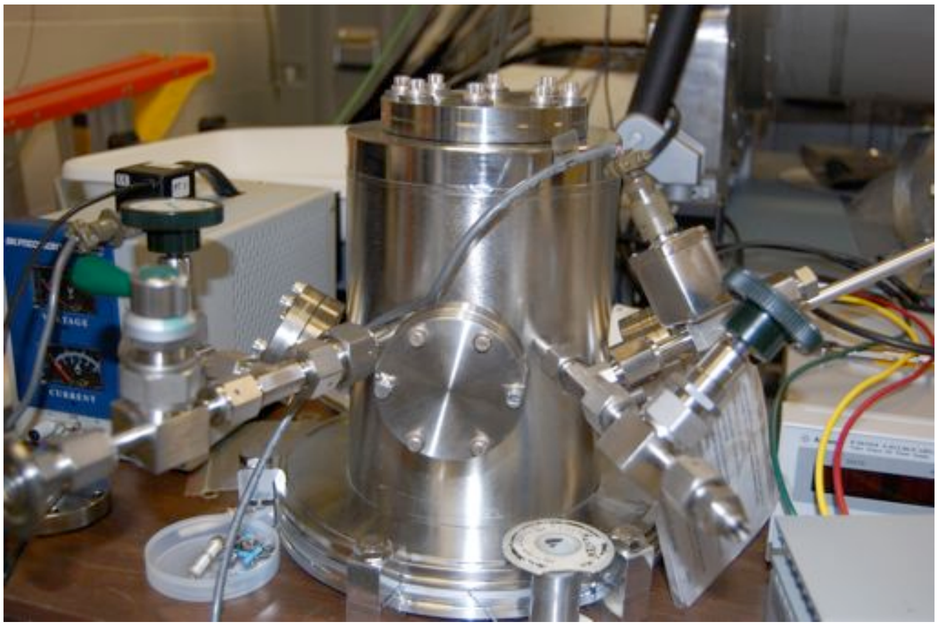

Figure 9: Shown here is the electron lifetime monitor vessel on the test bench at the LLNL TPC laboratory.

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 established a proven ability to furnish targets of ^{238}U, ^{235}U, ^{232}Th and ^{239}Pu on both thick (540 μg/cm^2 or 81400 μg/cm^2 Al) and thin (80-100 μg/cm^2 C). As of 4/2012, we have shipped ~50 targets to the TPC collaboration). The targets we have furnished have been used to perform the initial testing of the TPC.

Now we are entering into a second phase of target development for the upcoming run cycle (CY12-13) in which the TPC collaboration will perform a number of critical measurements of the TPC. To make these tests, we will need a set of special targets designed to allow definitive testing of the TPC performance. These new targets, which are being defined in April, 2012, will require unusual shapes of actinide deposits, variable thicknesses on a single target, the use of thin solid hydrogen containing targets and special deposit geometries to test the track reconstruction pointing accuracy. Some possible target geometries are shown in Figure 10 and Figure 11 (contributed by various members of the collaboration).

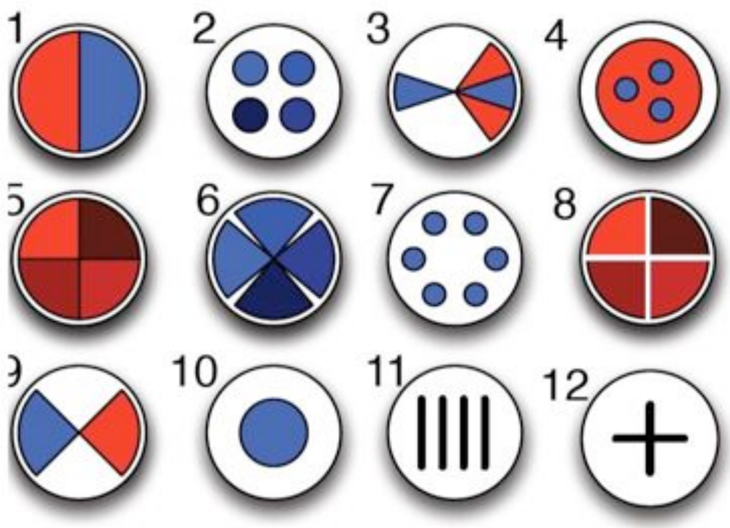

Figure 10: Some hypothetical target geometries.

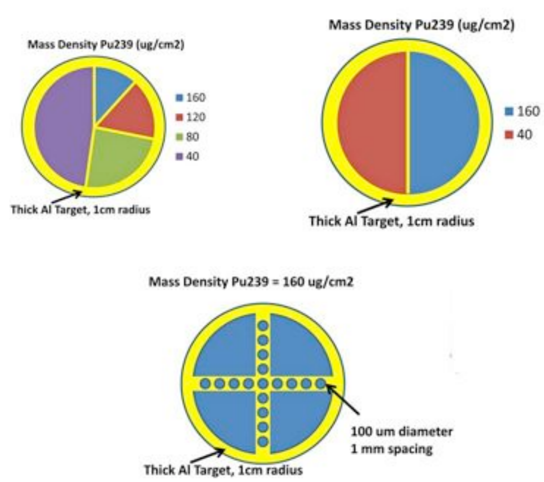

Figure 11: Some hypothetical Pu-239 target geometries.

Target Fabrication

To test our ability to construct these unusual target designs, we have made an initial test of our masking ability in target construction by constructing two “four leaf clover” targets of about 150 µg/cm2 235U on 81400 µg/cm2 Al. In Figure 12 we show one of these targets

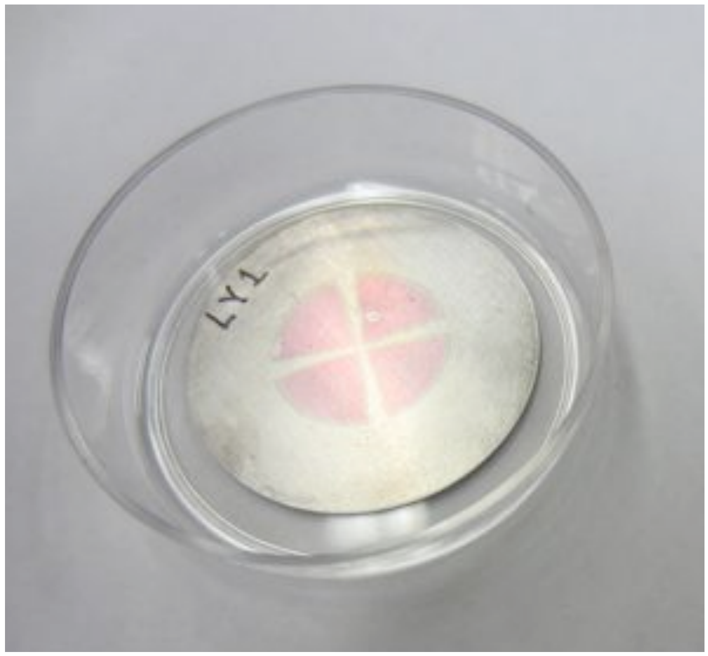

Figure 12: U-235 target with “four leaf clover” design.

Target preparation

The following routine targets were prepared and shipped to LANL:

(a) Two multi-isotope (^{235}U, ^{238}U) targets

(b) Four blank C targets

In addition, a new 10 μCi ^{252}Cf source (without any protective Au coating) was received. Four thin ^{252}Cf sources were made by self-transfer on 60 ug/cm2 Al_2O_3 foils. A typical activity was 400 fissions/min.

TPC Software [CalPoly, ACU, ISU, INL]

Scope

The TPC Software effort will include online and offline coding, FPGA programming for the data acquisition system, and simulation. In addition to reconstruction and analysis of data acquired by the NIFFTE detector, the offline simulation and reconstruction software will be used to generate substantial "Mock Data Challenge" datasets of simulated fission events, alpha decays and background events that will be processed through the full simulation and reconstruction chain. In addition to testing the readiness and functionality of the offline software, these MDC efforts are intended to improve modeling and design of the actual NIFFTE detector.

Highlights

- A new 3D Hough transform track finding algorithm was implemented in the offline framework and is currently being debugged and tuned.
- Updates to the reconstruction and tracking algorithms have been made for the U-238/U-235 ratio data collected during the last LANSCE beam cycle.
- A detailed analysis of the TPC codes was carried out to identify bottlenecks in processing the large TPC datasets.
- The online data acquisition software was further developed successfully for the high-rate Pu-239 data collection during the last LANSCE beam cycle.

Online Software [ACU]

The portion of this experiment's software library that is used during the data taking is called the online software. It overlaps in many ways with the data acquisition software, since it must take the data output from the readout cards after it has been processed with the FPGAs. The features that fall within the online 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.

Support for Operations at LANL

The online software has seen continuous development during the past quarter. Data collection at LANL was supported by installing, debugging, and maintaining the DAQ, slow controls, and online data quality assurance software. An important issue with the online demux performance was addressed. After analyzing some initial data with the TPC in the neutron beam, it was determined per-channel TPC trigger thresholds should be lowered to record significantly more recoil proton tracks from beam neutron interactions within the TPC.

Online Monitoring Maintenance and Development

The packet receiver and channel demux software were updated to handle waveforms from the HiSCaR. The event loop for the online channel demux software was modified to improve its data throughput capability.

The online event builder was modified and implemented to save a user controlled fraction of its output. For example, the program can save 100% of waveform events in when data rates are low or only 1% when rates are very high. This feature allows fine control over the amount of data passed to the CPU intensive online analysis and histogramming program.

MIDAS frontend program to store slow control measurements in the persistent SQL database has been updated to include recently added and modified channels. All the recorded variables are now saved with UNIX timestamp and the dates/minutes/seconds with time zone. This program was also modified to significantly reduce its CPU utilization.

Offline Software [CalPoly, ISU, INL, 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 offline 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.

Analysis Code Profiling

During the analysis of raw data from the 2011-12 LANSCE run cycle, it was quickly identified that the analysis was taking a remarkably long time to complete, particularly for the Pu239 data. It was not immediately obvious which part of the analysis chain was causing this, or even if it was due to a particular module in the chain, so a code profiling effort was undertaken to better identify any critical bottlenecks or inefficiencies.

Valgrind (www.valgrind.org) is an open-source programming tool suite capable of identifying memory leaks, memory cache use, and call tree profiling, among other things. It accomplishes this by first converting the original binary executable into a processor-neutral intermediate form, which is then run on a virtual machine. The resulting execution speed is 20-100 times slower than the original, but the executable otherwise performs identically. Complete call tree and memory usage statistics are collected and reported during the execution.

The profiling was performed for the full production analysis chain for 1000 events from the U and Pu run. Some results are shown in Table 1 and Table 2.

Function	**Percent of total execution time**
NiffteRootIO::WriteEvent	40.8%
TPCHoughD::ProcessEvent	27.5%
TPCKalman::ProcessEvent	25.1%

Table 1. Percent of total execution time for selected functions in the NIFFTE production analysis chain, as reported by Valgrind.

The obvious conclusion from Table X is that writing the events to disk is taking a significant portion of the total analysis time. CalPoly collaborations quickly identified that NIFFTE data is stored in C standard template library arrays, but could instead be stored in ROOT TArrays which would reduce the amount of data reformatting required when writing events to disk. Preliminary estimates of switching from STL arrays to TArrays in the NIFFTE analysis code implied a potential speedup of 2.8x; see the corresponding subsection for more details on that analysis.

Function	Percent of Hough execution time
ceil	5.6%
cos	31.2%
sin	30.2%
ResetHistogram	10.8%

Table 2. Percent of total execution time for selected functions in the NIFFTE production analysis chain, as reported by Valgrind.

Once the data storage format has been changed, the file I/O should drop to roughly 20% of the total execution time, and the optimization of the analysis code will become more important. Table Y demonstrates areas of potential improvement for the Hough track finder. In particular, standard library calls for sine and cosine trigonometric functions take over half of the processing time. Provided that the required resolution is achievable, this could be significantly sped up by replacing the function calls with a lookup table. As another example, the ResetHistogram() function simply clears the contents of a histogram to zeroes, but the existing code was using an inefficient nested loop to do so.

Several easy optimizations are also present in the Kalman filter module. Improved code for the issues described above are being submitted for the next release of the analysis code, and Valgrind will be used to continue optimization of the NIFFTE production chain.

Track Reconstruction using the Combinatorial Hough method

The software profiling work identified the Hough subroutine as a place for some performance improvement. The Hough subroutine identifies hits in the TPC that fall on the same line in 2D space. The Hough transform maps points in (X,Y) space to a polar coordinates space (ρ,θ) where lines are represented by angle and offset from the origin. The idea is that points that fall on the same line in (X,Y) space will map to the same point in the (ρ,θ) space. Searching the (ρ,θ) space for the most intense regions will give the points (digits in the TPC analysis language) that are all on the same line. Some minor inefficiencies in the search and initialization routines were identified and fixed. Those resulted in only minor performance improvements. The major inefficiency in the code is fundamental to the routine and involves filling the (ρ,θ) space with the family of lines that all go through the (X,Y) point. The number of lines allowed to pass through that point should be large for precision results but small for the routine to complete quickly. By definition, the vast majority of the looping will be for lines that are not representative of the data.

A potentially faster method is to use the Combinatorial Hough transform. Instead of cycling through hundreds of lines for each point, each pair of points in the collection of digits for a particular event is cycled through and the (ρ,θ) points representing the line between those points are recorded. Again, the most intense region of (ρ,θ) space then represents the line that encompasses the most points. This method will contain fewer iterations as long as the number of digits remains less than half of the number of lines tested in the original algorithm. For events with small numbers of digits, the Combinatorial Hough routine should be substantially faster.

A study was performed to test the performance improvement. The results for both track reconstruction routines were compared using the first 1000 events of a typical uranium target run (400000487) and the first 1000 events of a typical plutonium target run (400000838). The results of the study are shown in Table 3. The Combinatorial Hough method is certainly faster and the improvement is even more for the Pu data. Due to the large intrinsic activity of the plutonium, a higher detector threshold was used resulting in shorter stored tracks. These shorter tracks have fewer digits and so the percent improvement is larger for the Combinatorial Hough as would be expected given the two routines different dependencies on the number of digits mentioned above.

Table 3. Study of the time to convert from a raw file and perform track reconstruction for the first 1000 events using the original Hough and the Combinatorial Hough routines for the two different targets.

Target	Time to execute with Original Hough (s)	Time to execute with Combinatorial Hough (s)	Percent improvement
Uranium	9.17	7.65	17%
Plutonium	6.72	4.22	37%

An initial assessment of the performance of the Combinatorial Hough was completed. In some regions of the phase space there was good agreement between the original and Combinatorial routine while in other regions, there was less agreement. However, an examination of the tracking results for both algorithms reveals that neither is optimal yet. There are adjustments and optimizations that need to be made to both algorithms to allow for more reliable track reconstruction. Examples of the necessary adjustments are the weighting method used for each event, the width of the tracks, and the coarseness of the (ρ,θ) space. Further study has begun using simulated data to compare the strengths and weaknesses of the two routines and hopefully lead to improvements in the algorithms. The initial particle conditions are better controlled in the simulation which allows the different algorithm behaviors to be examined in more detail.

Tracking Algorithms

A new 3D Hough transform track finding algorithm was implemented in the offline framework and is currently being debugged and tuned. Initial comparison between the new and old algorithm vs. Monte Carlo simulations indicate that we can expect some improvement in tracking accuracy once the new algorithm is optimized.

Offline Utilities and Data Processing

A web-based software to manage shifts for the LANSCE run was installed and configured, and an extenisve shift page was setup for shifters. The shifts have been going well and we are getting good participation from folks to run the shifts around the clock.

New bug tracking system (TRAC) is installed and in use to track and prioritize both software and hardware related issues.

Automatic data transfers form LANL to LLNL are now in production mode. Run data is archived on tape within 2 hours of being taken.

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.

Software Updates

The online software was used extensively during the WNR operation period by remote shifters and local operators. Monitoring for EtherDAQ status, TPC data rate, and Ethernet traffic helped to identify several cases of degraded communication with multiple frontend DAQ cards. The hardware configuration change that coincided with these communication issues was reverted.

The overall data rate from the U238 and U235/U238 wedge combo targets is 200 kB/s with properly defined trigger threshold. The beam trigger mask was not completely deployed for this run cycle so the threshold was set very high to reject most of the alpha background in most of the Pu data runs. In this case, it turned out the data rate was at 700 kB/s as seen from Figure 13. Effort was taken to record data with low trigger thresholds for the Pu target as well to test the performance of the whole system chain. Thresholds are set up as 4up, 3 down for most of the channels while few noisy channels were configured with slightly higher thresholds. Figure 14 shows the reconstructed track length vs ADC from a part of a low threshold run. As expected, it appears that the most events are from alpha decay.

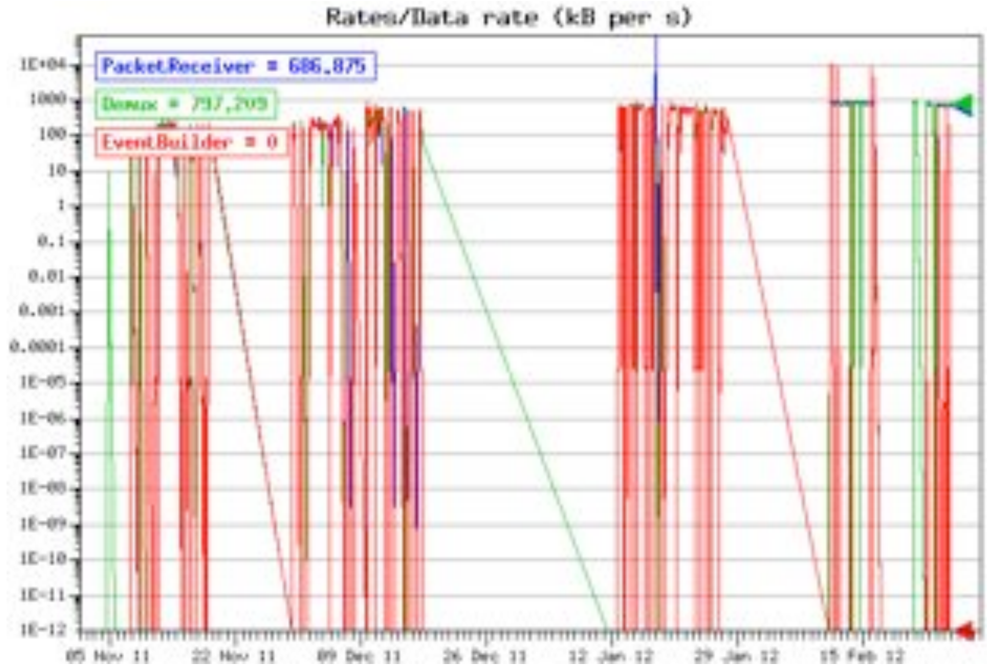

Figure 13: Shown here are the data rate monitoring for the run period.

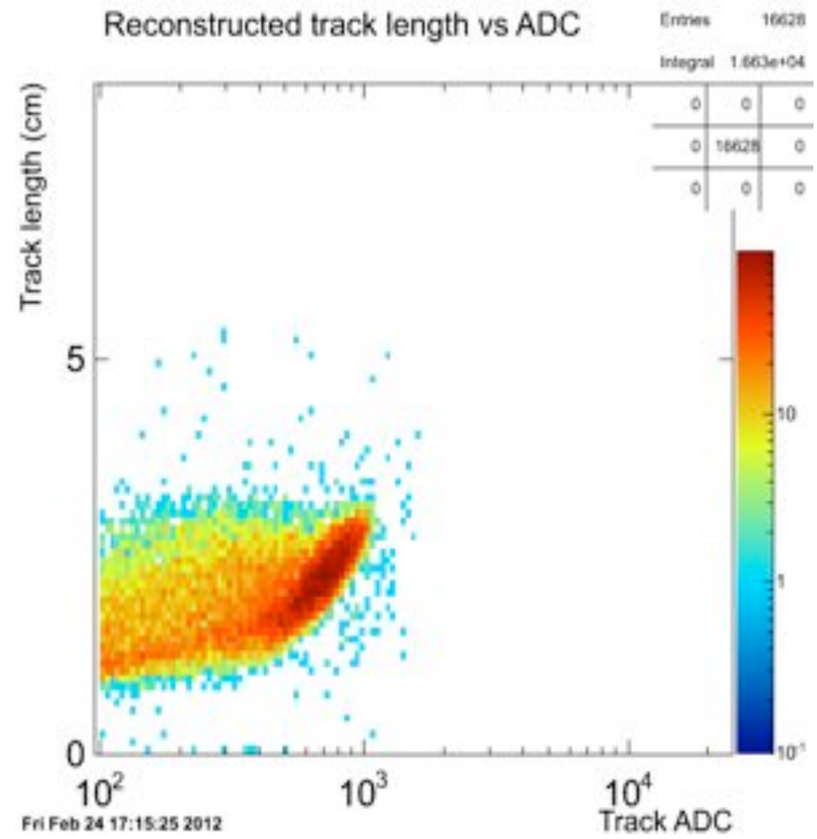

Figure 14: Shown here is the reconstructed track length with the ADC distribution from a portion of a low threshold Pu run from online monitoring. The run conditions were: pressure 972 torr, FCT/FCB/MMG -1200/-339/-340 V, average beam current 1730 nA, Lookback=65.

Simulation [ISU, LANL]

Scope

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 known 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.

Highlights

- New highlights

GARFIELD Simulations

As mentioned in the previous quarterly report, a particular type of track defect was identified for fission fragments, where a much slower data collection rate occurs for a subset of the charge. The hypothesis presented at that time was that the much larger number of electron-ion pairs being generated by fission fragments was resulting in a significant ion cloud in the region of the track, which was affecting the drifting electrons. An example from actual data is shown in Figure 15.

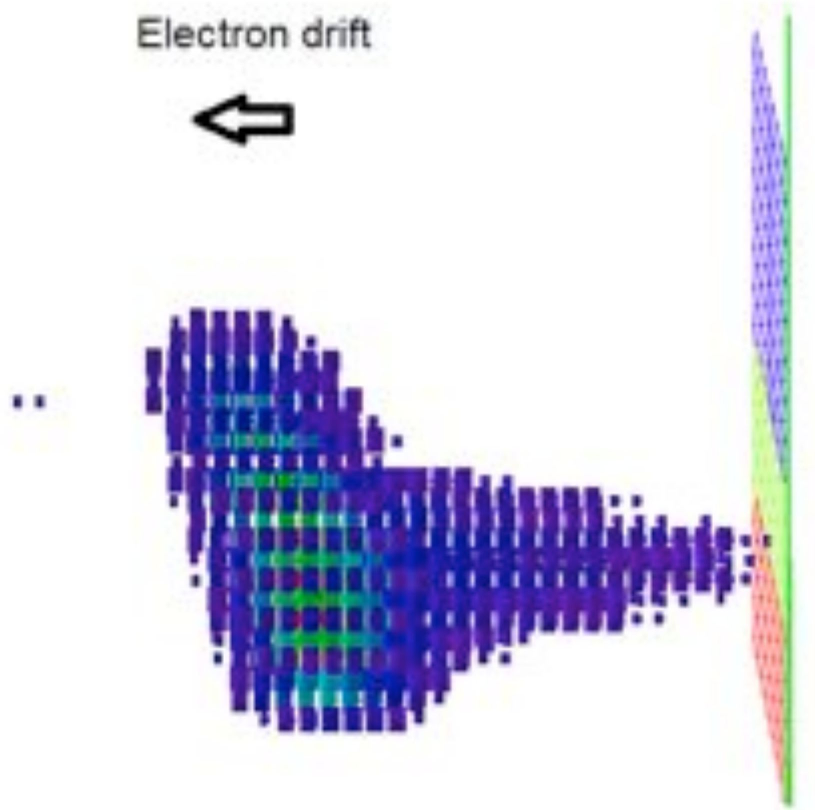

Figure 15. Example of the delayed drift time effect in actual data (electron drift and collection occurs to the left). The "tail" of charge to the right of the track actually represents electrons arriving later than expected. The track has incorrectly identified it as a separate track.

To better study this, a simple GARFIELD simulation was run, with the simple geometry of two 8 cm x 8 cm plates with voltages of 0V and -840V placed 5.5 cm apart representing the TPC. Provided that the drifting electrons stayed near the center of the plates, then the lack of field cage had only a minor effect on the simulation. To get around limitations of GARFIELD, which assumes that all defined shapes are solids and thus block electron drift, an electric field was calculated with an external tool and imported into GARFIELD. The finite element analysis tool Maxwell was available and used for this effort.

With Maxwell, cylindrical charge clouds of radii from 10um out to 100um were generated horizontally, and electrons drifted from a line below and perpendicular to the cloud drifted past (and through) it. If the hypothesis was correct, then electrons that drift through the cloud should show longer drift times than those that drift some distance from it. Figure 16 shows results for radii of 10um, 25um, and 100um.

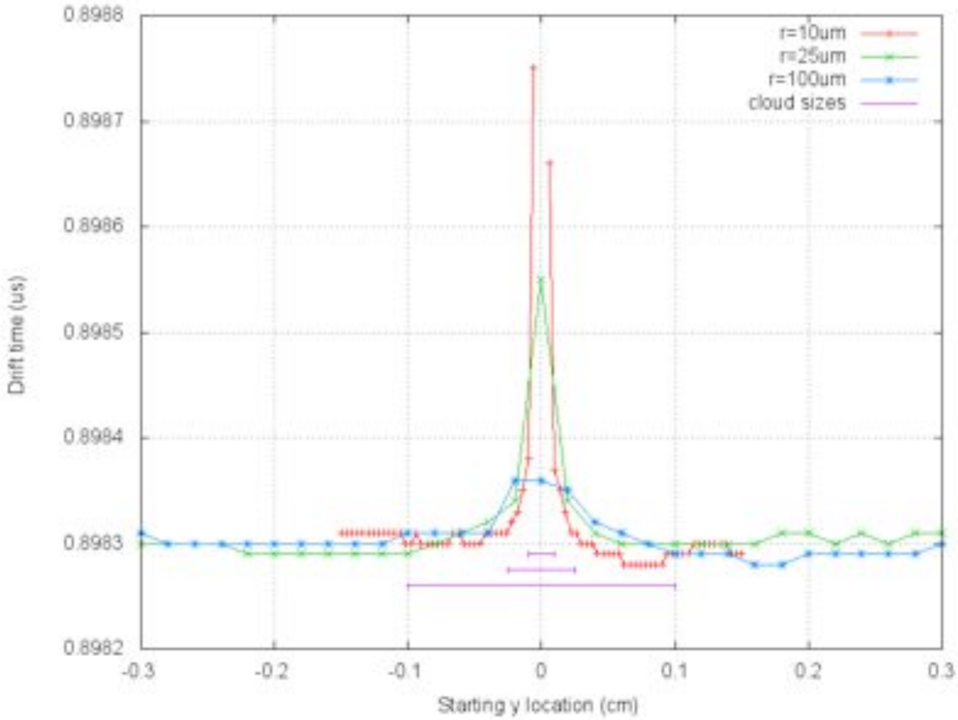

Figure 16. Calculated drift times for electrons drifting

While it can be seen that electrons that pass through the charge clouds have longer drift times, and the drift times increase as the charge cloud radii decreases, the effect is only about 1/1000 as large as has been identified in the actual data.

Investigation of the parameters used in these simulations is underway to identify any potential errors in the analysis. In addition, analytical estimates of the effect are now being undertaken to confirm the magnitude of the effect as seen in simulation.

Data Analyses [CSM, LANL, CalPoly, ISU]

Scope

The TPC data is analyzed early in the program to validate operation and design choices. The early analyses include data collected using partially instrumented instruments, using sources and neutron beams, including the proto-type TPC as well as the production versions. These analyses are used to test the complete system and to determine the overall quality of the data through the complete hardware and software chain.

Highlights

- Analysis of the U238/U235 data collected at LANSCE is underway.

- The second Ph.D. was granted to a TPC researcher for work on the Cf-252 alpha decay to spontaneous fission ratio, a critical TPC performance benchmark. Although taken with only a single sextant instrumented, demonstrated that the TPC, even under these less than ideal conditions, is already comparable with the uncertainties on what is considered a well-measured benchmarked.
- The online monitoring system performed well during the last run cycle and provides researches with most of the LANSCE performance information needed for these exacting measurements.

Cf-252 Alpha Decay to Spontaneous Fission Branching Ratio

Working toward the goal of developing robust particle tracking and identification capabilities, the fission TPC is being used to measure the alpha/SF branching ratio in Cf-252. An initial analysis of the Cf-252 data is complete and the branching ratio was measured to within 1% of the accepted value. The measurement of alpha/SF was completed with 1 sextant of the TPC instrumented, or 1/12th of the total detector, and a 100 nCi Cf-252 source mounted on a platinum backing. This is a challenging exercise as the limited fiducial coverage leads to effects that constitute the major contributors to the overall systematic errors in this particular study. A fully instrumented TPC will not suffer from these limitations.

The source composition was determined by measuring the alpha decay spectrum of the source with a silicon diode detector. The alpha and fission spectrum of the Cf-252 button source as measured by the silicon diode detector can be seen in Figure 17. The source activity was determined to be approximately 97.3% Cf-252 at the time of the measurement. The alpha/SF branching ratio was also extracted from this data and was found to be within 1% of the accepted value.

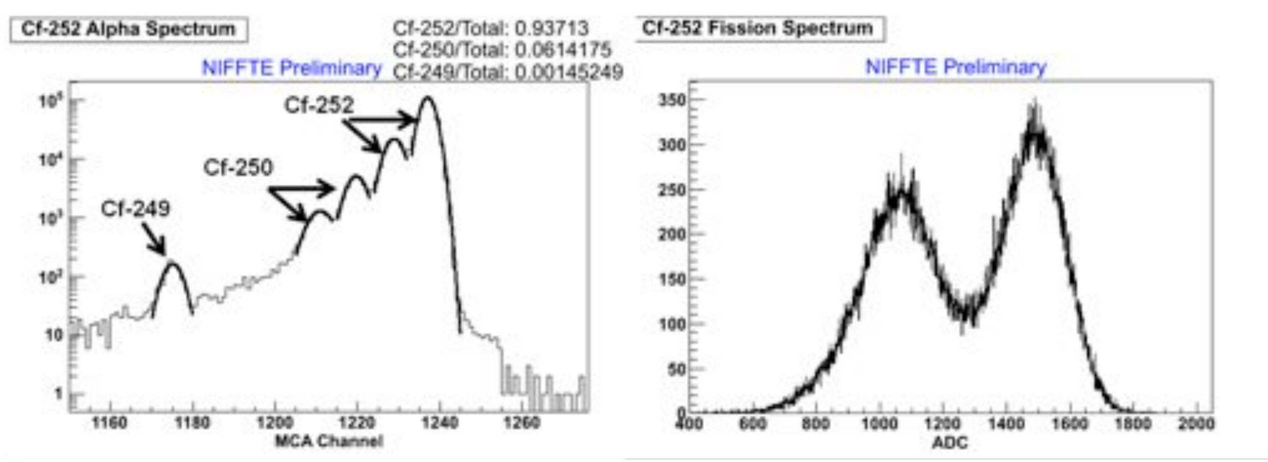

Figure 17: The alpha spectrum of the Cf-252 button source as measured with a silicon diode detector. The plot on the left shows the alpha spectrum, the y-axis is in logarithmic scale. The plot on the right is the fission spectrum. The expected major contaminates were Cf-249 with an alpha energy of 5.813 MeV (82.2\%) and Cf-250 with alpha energies of 6.030 MeV and 5.989 MeV (84.6\% and 15.1\% respectively). The expected alpha energies from Cf-252 are 6.118 MeV and 6.075 MeV (84.2\% and 15.7\% respectively). These five peaks are fit with Gaussian functions. The ratios shown on the top right the alpha spectrum plot is the area under the associated peaks divided by the total of all the peak areas.

SRIM simulations and published data were used to account for the effects of the scattering of alpha particles and fission fragments in the source. The Cf-252 source was mounted on a thick platinum backing and covered by approximately 100 μg/cm^2 of gold. In principle the available solid angle for emission from the sources is 2π, however it is not expected that the detection efficiency will be 50% due to the effects of scattering in the source backing and cover. Alpha particles (and in the case of the Cf-252 source, fission fragments) incident upon a metal backing will occasionally scatter through a large angle due to an interaction with a nucleus (Rutherford scattering), and be emitted from the surface of the source and into the active area of the detector. Even more often than Rutherford scattering, an ion will undergo multiple scattering at small angles with the atomic electrons, the cumulative effects of which can result in backscattering, particularly if the initial trajectory of the ion was at a grazing angle with the surface of the metal backing. In this context then, backscattered refers to an ion with and initial velocity vector towards a surface which then scatters and is left with a velocity vector away from the surface, not necessarily an ion that is scattered through an angle greater than 90 degrees. Figure 18 shows the polar angle distribution of alpha particles from a TRIM simulation of a 4π alpha point source mounted on a thick platinum backing and covered by a thin gold foil, also shown is the data from the TPC. The active volume of the TPC was defined to be between a polar angle of 90-180 degrees, where the polar angle is the angle with the axis that is perpendicular to the plane of the source. An ideal point source would then be expected to have a flat distribution of tracks as a function of the cosine of the polar angle. The simulation and the data both show a predominance of tracks near a cosine of zero, which is near parallel with the surface of the source. This is a result of alphas that have backscattered in the platinum backing and then been transmitted through the active, gold covered side of the source.

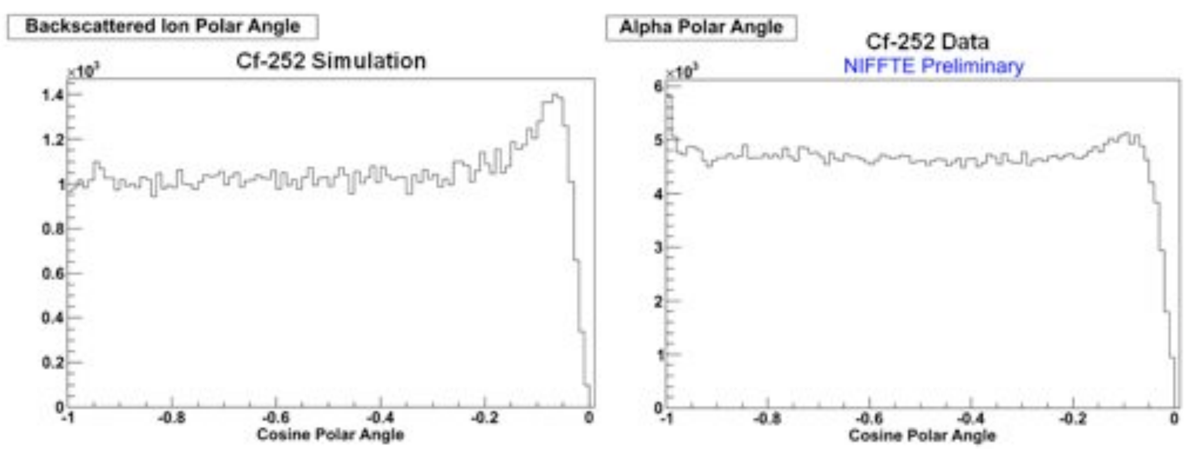

Figure 18: The left plot is a simulation of the Polar angle distribution of the alpha particles that have either been transmitted directly through a 100 μg/cm^2 gold covering or backscattered off a thick platinum backing and then transmitted through the thin gold covering. The simulation was based on a 4π point source of 6.118 MeV alpha particles positioned between the gold covering and platinum backing. Note the peak in the count rate near cosine equal to zero, which is a result of excess particle tracks from backscattering. The Plot on the right is the polar angle distribution of alpha tracks in the TPC. A similar peak in the count rate near cosine equal to zero to the one in the simulation is exhibited. The polar angle is defined as the angle with the axis that is perpendicular to the surface of the source. Cosine equal to zero then is parallel to the surface of the source.

Figure 19 shows the length vs. ADC of fission fragment and alpha particles in the TPC. Graphical cuts show the number of alpha particles and fission fragments and the ratio of the two numbers. The branching ratio shown in the graph must be multiplied by a factor 2 to account for the fact that with a 2π source there are at least two chances to detect every fission event. Doing so will give a ratio of approximately 33.36 which is higher than the expected value of 31.34. The ratio has not been corrected for backscattering however. Due to the high nuclear charge of fission fragments, they are generally more susceptible to backscattering than alpha particles resulting in the ratio being higher than expected. The details of a backscattering correction will not be discussed here, but after applying a preliminary correction a ratio of approximately 31.08 – 31.19 is calculated (the exact value depends on the details of the application of the backscattering correction). While this value is preliminary, it is within 1% of the accepted value of the alpha/SF branching ratio of Cf-252. Considering the limitations imposed by having a partial detector and the use of a non-optimum source (i.e. the thick platinum backing which causes backscattering), the results are quite good and go far in confirming the abilities of the fission TPC to track, identify and distinguish alpha particles from fission fragments.

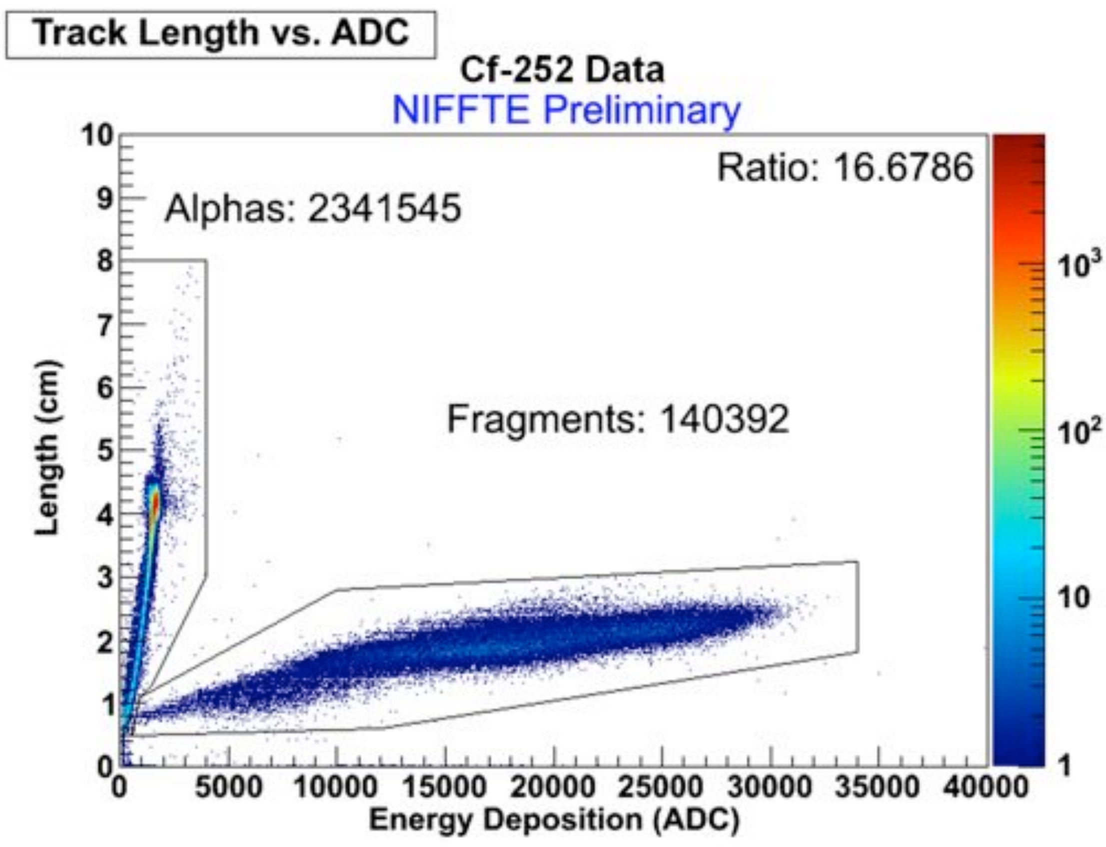

Figure 19: The track length vs. the ADC of particle tracks in the TPC. The color scale is logarithmic. The band on the left at low energy with long track lengths are alpha particles, while the high energy short tracks are fission fragments. The number of fission fragments and alpha particles are based on the graphical cuts drawn. The tracks were between 35 - 85 degrees azimuth and 90 to 180 degrees polar.

Luke Snyder from the Colorado School of Mines defended his PhD thesis successfully in March based on the first data from the one segment (1/12) operation of the NIFFTE TPC. His thesis describes an analysis of the alpha to spontaneous decay channel ratio in the nucleus 252-Cf. His results are compatible within error (experiment achieved competitive precision) with previous measurements. Additionally, due to the tracking capabilities of the TPC it was possible for the first time to directly measure the fraction of back-scattered particles originating from the platinum source backing. Given the complex geometry of the partial detector the analysis was very successful and provided an excellent start to the physics program of NIFFTE.

WNR Data Collection

There are total 950 runs (846 physics runs) of data collected with raw pcap data file size of 2.18TB (2,183,313,959,341 Bytes). Figure 20 shows the run number versus the raw data file size. At the end of the run cycle, effort was taken to collect the Pu beam data with low threshold. It turned out the data rate went up to ~100MB/s. Few short runs with low threshold were successfully taken with 25GB in about 5 minutes each. The average beam current is in about between 1500 and 1700 nA and is stable during operation period (Shown in Figure 21). The performance of TPC electronics shows very stable and calm, the warmest card temperature recorded was never above 38 degree (Shown in Figure 22).

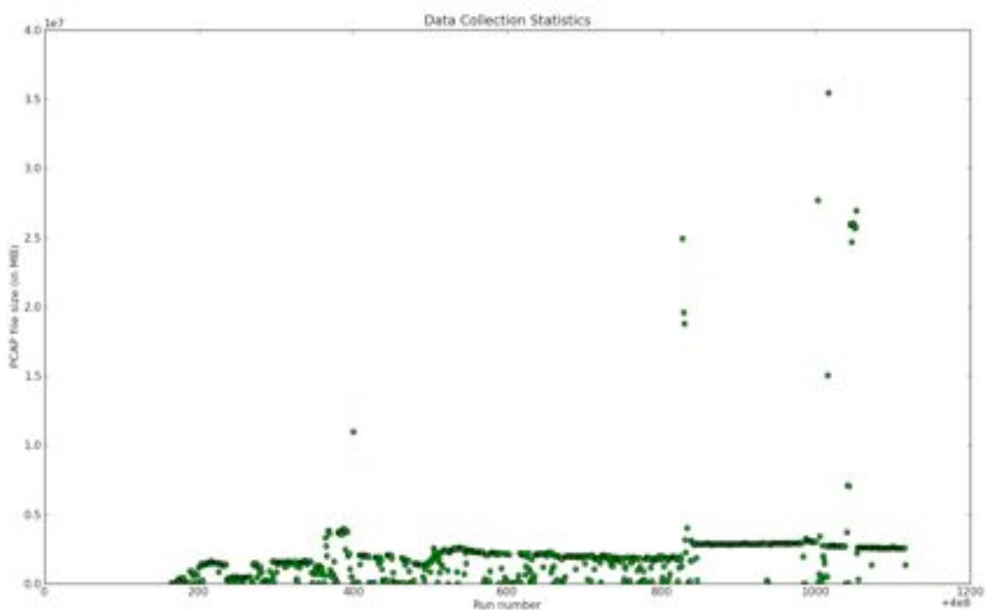

Figure 20: Shown here are the data statistics versus run number.

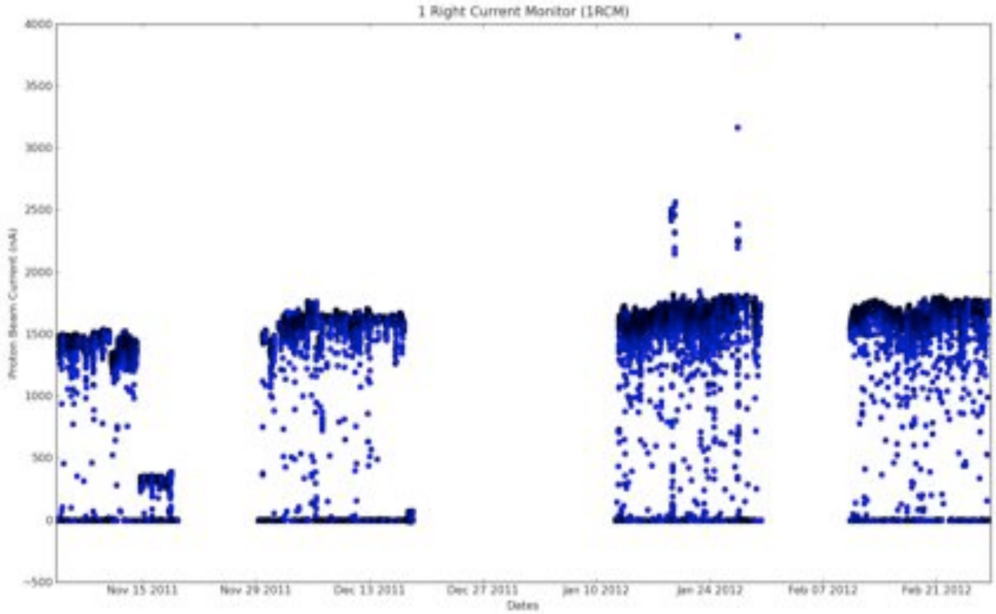

Figure 21: Shown here is the beam current monitoring at the 1 Right path..

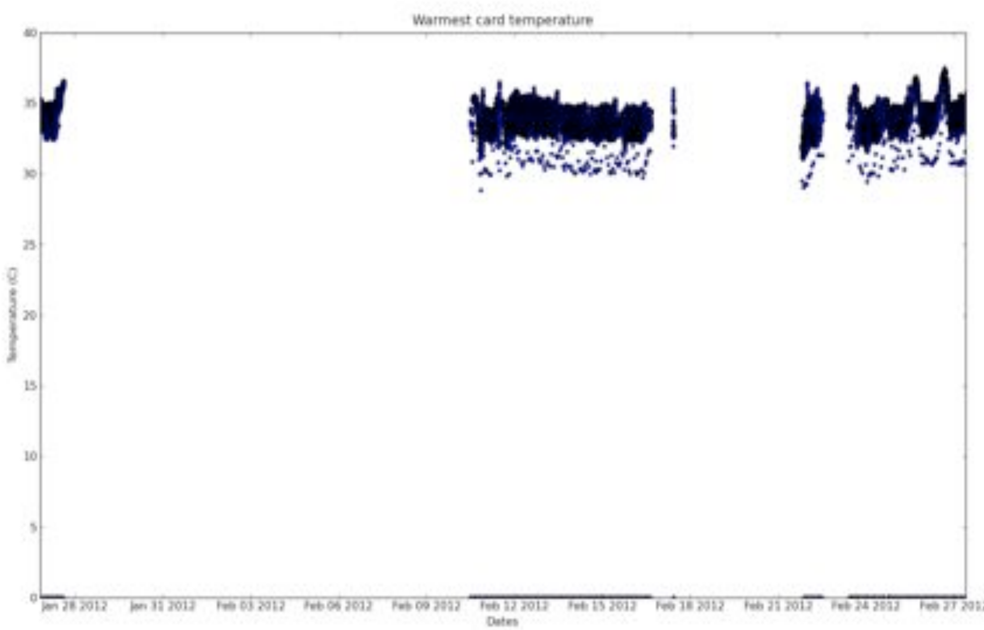

Figure 22: Shown here is the warmest EtherDAQ card temperature variation during data taking.

TPC Data Analysis

The particle ionization characteristic from both Pu and Uranium data has been studied to better understand the detector performance, such as the space charge effect from the track density inside the TPC gas volume. Figure 23 shows the specific ionization of alpha tracks from both data set. The overall shape of the ionization along the track looks similar while difference shows at the beginning part of the track. The dE/dx shape is lower near the start part of the alpha track from Pu data compared to the alpha track from Uranium data. It could due to some kind of attenuation of drift electrons by gas ions created from high density tracks per unit time for the Pu compared to Uranium. The effect seems to be most significant at the beginning of the track where the drift electrons travel the longest distance to pad plane. Similar effects may be present in recoil proton and fission fragment events but is not distinct for the much smaller deposit energy of proton and the more complicated space charge effect of the fission fragment.

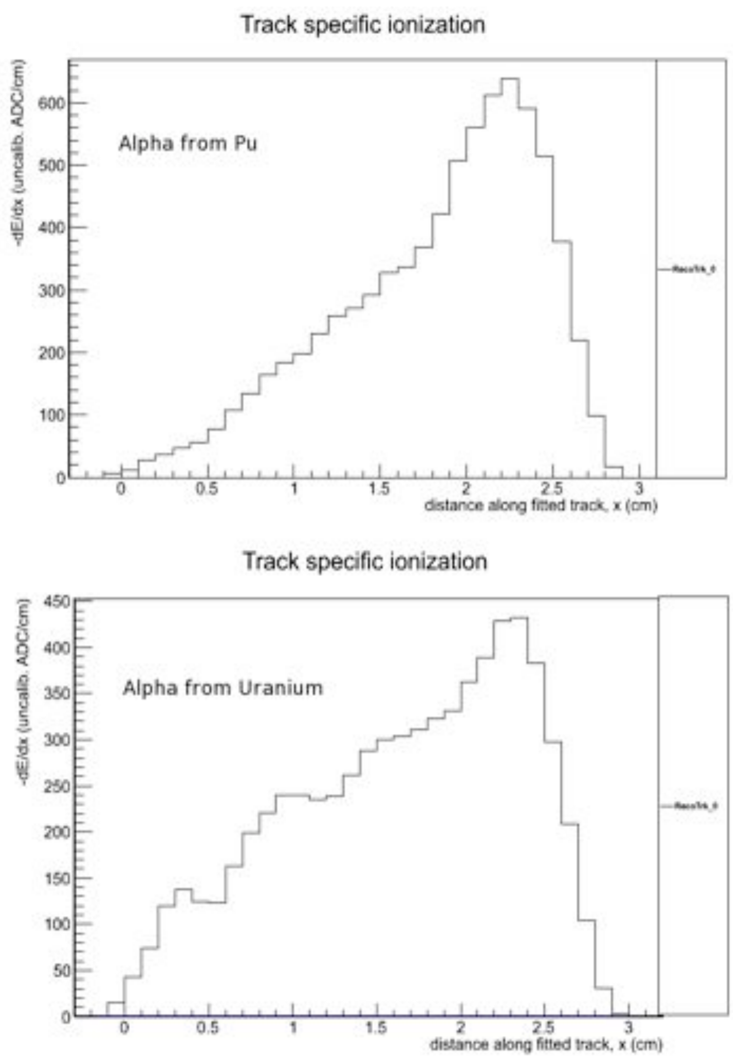

Figure 23: Shown here is the deposited energy per unit length along the reconstructed track of the alpha from the Pu and Uranium data.

The Hydrogen Standard [OU]

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 to 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

- A report was developed that will be used in developing the solution for a fixed-energy neutron source for systematic uncertainty studies.

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 in statistical improvement. This may reduce the experimental running time for a 1% measurement from 3 months to days. 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}Li(n,α)^{3}H, ^{10}B(n,α)^{7}Li and ^{235}U(n, f).

Setting up for Monoenergetic Neutron Measurements

At the June collaboration meeting a suggestion was made to plan for monoenergetic neutron runs. The initial suggestion was two runs of two weeks at two different neutron energies to collect data on the ratio of the cross sections, U-238 to U-235. More recent plans have been made for measurements of up to at 12 energy points for data on the ratio of Pu-239 and U-235 cross sections. Figure 24 shows the ENDF/B-VII.0 Pu-239 and U-235 cross sections with potentially useful energy points for measurements.

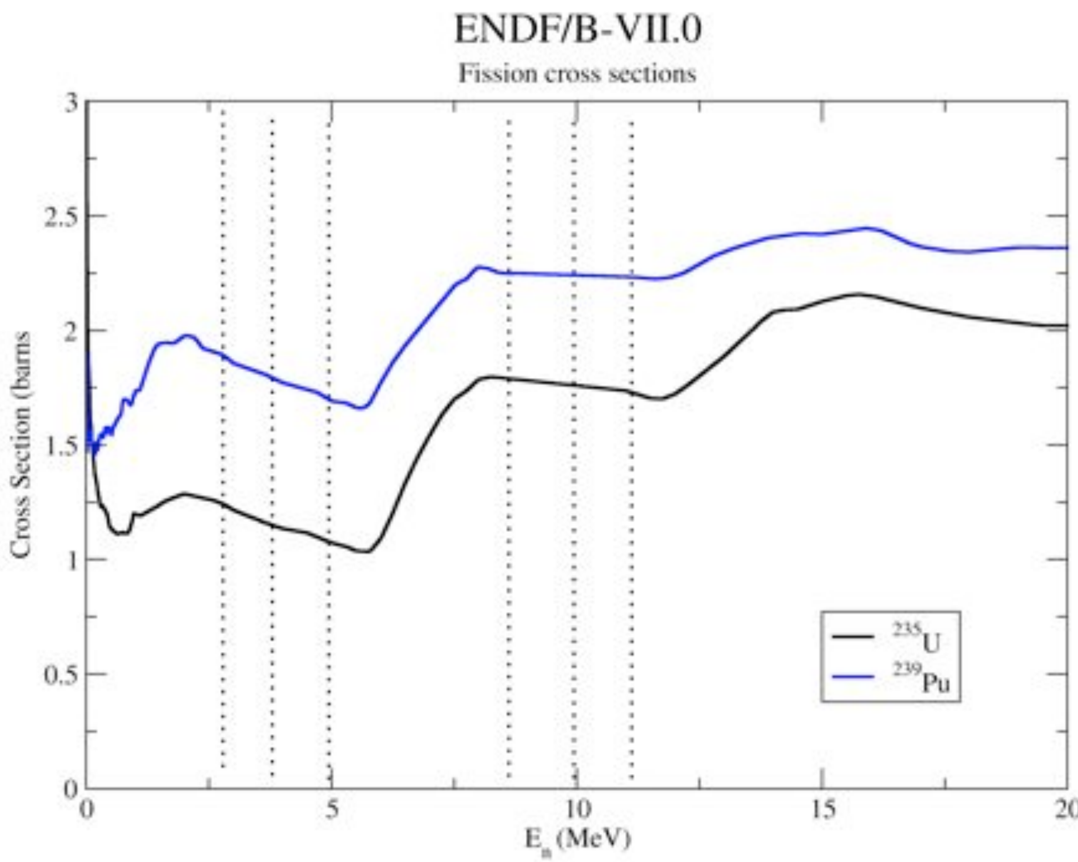

Figure 24: ENDF Evaluations of the ^{235}U and ^{239}Pu fission cross sections. Regions where monoenergetic ratio measurements would be useful are shown by the dotted lines.

Several factors need to be considered to determine the feasibility of the proposed measurements - facility, safety, beam availability and neutron production targets.

We have reviewed the accelerator laboratories in the United States that can produce the pulsed proton or deuteron beams needed for the generation of neutrons for the TPC measurements. Since the 1991 DOE report[i], many of the U.S. accelerator laboratories have ceased to exist as functioning labs. These have included the California Institute of Technology Pelletron Electrostatic Accelerator, University of Massachusetts-Lowell, Yale University Tandem Lab, University of Pennsylvania Super FN Tandem Van de Graaff Accelerator, Princeton University – Cyclotron Accelerator, University of Rochester-Nuclear Structure Research Laboratory. In Table 1 are the accelerators in the US capable of providing pulsed and bunched beams of protons and deuterons in the energy range of interest.

Table 4: Current United States Accelerator Facilities with pulsed beam and proton and deuteron beams.

Facility	Mass Range	Energy Range	Pulse width	Energy Resolution	Intensity
Triangle University Nuclear Lab	1-4	0-20 MeV	1 ns	0.001 %	5 p μA
University of Washington Tandem and Booster	1-56	0- 18	~1 ns	0.01%	50 p μA
Florida State University Tandem-Linac	1-56	1-18 MeV	~ 1ns	0.01%	30 na
University of Kentucky- Single ended Electrostatic Accelerator	1-4	0-7 MeV	0.25 ns	0.001%	1ma - 200 p μA
University of Notre Dame –Tandem Accelerator	1-50	1-16 MeV	1.0	0.001%	11 p μA
University of Wisconsin – Wisconsin EN Tandem Accelerator	1-4 +	1-13 MeV	1 ns	0.001%	1 μA
Ohio University Accelerator Laboratory	1-16	0.5-8 MeV	0.6 ns	0.001%	1 p μA
Idaho State University	1-4	0.5-8 MeV	1 ns	0.001%	200 p μA

Support capabilities, in addition to the pulsed and bunched proton and neutron beams, need to be available to provide the intensity for full suite of data needed by TPC project. Neutron production technologies such as gas cells or solid targets are well developed and can easily be transferred between laboratories. However, these technologies are limited to charged particle beam currents of 10 μA or less due to heat load failures.

Advanced neutron production methods exist for higher beam currents. Argonne National Laboratory has produced a lithium water-fall target[ii] designed for neutron production at a beam current of 80 μA. We have used a conductive transmission plate with 0.070" holes drilled in a close packed array to support a target foil. Our experience with this foil is that that it survives 10 μA beams at 2 atmospheres. This design must be extended to the current range from 10 μA to possibly 100 μA by reducing the thermodynamic stress on the foil. There are also a number of publications for gas jet target targets, as was developed and used at MIT[iii]. A plasma window gas cell was investigated by Gerber[iv], but was not used beyond the testing phase.

A major criterion for choosing a facility for work is the radioactive licensing for tritium and the actinide TPC samples. In order to use the T(p,n) or the T(d,n) reaction, a license for tritium gas or solid target is required. Of the accelerator laboratories listed in Table 4, only Ohio University and Kentucky University have current tritium licenses. The actinide licenses can easily obtained give time and interest. Ohio University has had the clearance for the planned samples for over a decade.

The TPC measurements will require a flux of roughly $1x10^6$ neutrons/cm^2/sec). This results in a dose at the target of 156 Rem/hour for 5 MeV neutrons. At the proposed TPC location the dose will be 1.56 Rem/hour. However, radiation limits to general public must be less than 0.1 Rem. The facility thus needs to have sufficient shielding for this high neutron dose or move the TPC experiment to a very large distance from the target area.

The electronics will also need to be shielded from the high neutron dose. This can be accomplished with a collimation assembly. Ohio University has started the design of a collimator for a TPC located 0.5 m from the target (see Figure 25). The collimator assembly could be transferred to another laboratory, if needed. Our experience with computers located in the neutron fields of the Large Target Room at OUAL is that one to two upsets/day occur. The dose to the electronics must also be considered in the siting plan of the TPC system. Of the laboratories on the list, only University of Kentucky and Ohio University (possibly Triangle University Accelerator Laboratory) have the necessary shielding on hand. A proposal to add shielding to the collimator is shown in Figure 25. The addition of iron and water to the collimation would likely reduce the room neutrons. Addition of borax should also reduce the thermal neutron flux that is known to cause upsets in computers located in the same room without shielding. This will have to be modeled in MCNP to determine if this has any effect on the neutron spectrum seen at the target position of the TPC.

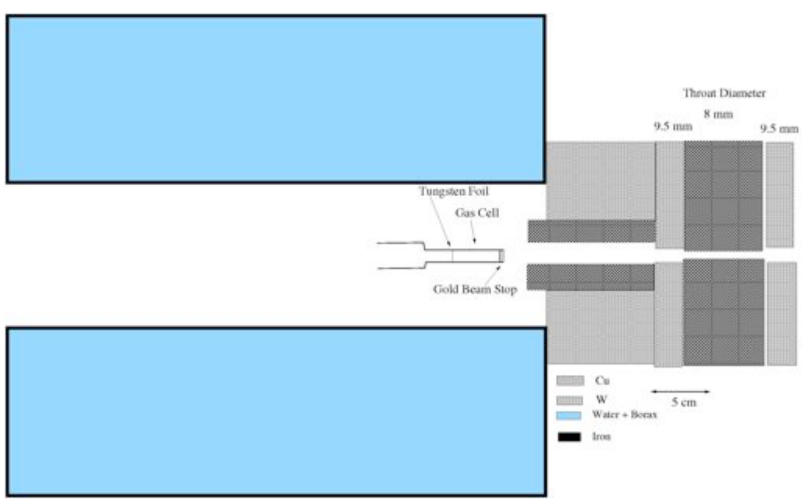

Figure 25: The proposed collimation and shielding at OUAL for the TPC at 0.5 meters from the source reaction. Additional shielding will be added following planned MCNP calculations.

If there is sufficient flux at a 4 meter distance, OUAL is the best choice for these measurements. The swinger and time-of-flight tunnel together allow flexibility of experiments and very low room return backgrounds. A diagram of the collimation to be used in this case is shown in Figure 26.

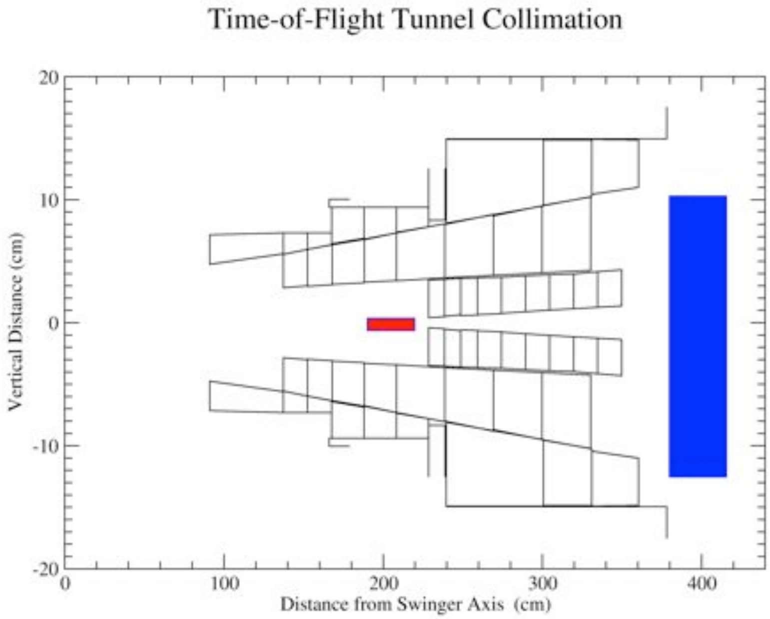

Figure 26: Tunnel Collimation set shown for all collimators in place. The outer set is high-density nylon and the inner two are fabricated from polyethylene. For normal operation the gas cell would be located at the axis. If a beam line extension with a steering quadrupole is installed a gas cell (red) or other neutron production target can be placed closer ~2 meters from the TPC (shown in blue).

The infrastructure needed for the TPC is primarily power and Ethernet. The Ethernet and power are available at both locations considered at Ohio University. Additional requirements are handling the working gas of the TPC. We have handled similar problems previously with the fission chambers used for neutron flux measurements. Mechanical supports and integrated facilities for both the electronics and gas system are available at OUAL and would require some time to be developed at other facilities. Three separate fission chambers for testing of the neutron flux are also available at OUAL.

The background for some of the reactions may need to be simulated. The D(d,n) reaction is as strong generator of neutrons but has additional neutron produced by the D(d,pn)d breakup reaction. A double neck gas cell has been developed to measure the primary spectrum by the D(d,n) reaction and mock up the background using the 3He(d,pn)3He reaction. This has been shown[v] to be very effective for experimentally correcting for this background. This is available at OUAL but is portable if it is needed elsewhere.

A clean hood is a requirement at any laboratory. This is needed to assemble the TPC in a clean room environment for proper operation. This is critical for the successful operation of the TPC as dust and foreign material will cause unwanted discharges from the high voltage areas.

If the actinide targets are thin and fragile, a glove box also maybe required. The alpha contamination from a single broken foil would shut down the facility until the contamination has been cleaned up. We do not currently expect to be using thin targets with a monoenergetic neutron beam.

There is good reason for continuing to look at other facilities for future measurements. The Idaho State University tandem accelerator could reduce the measurement time by an order of magnitude if a shielded experimental facility can be built. The Triangle Accelerator Laboratory has the capability of higher energy neutrons from the d(d,n) reaction, but a shielded experimental facility would also need to be constructed. The Kentucky University Accelerator Laboratory can produce a mA of beam up to 6 MeV in energy using a single ended van de Graaff. This may be very useful if a shielded facility for the TPC can be constructed.

Ohio University Accelerator Laboratory

This accelerator has been designed specifically for neutron measurements. The accelerator was designed for a maximum terminal voltage of 5.5 MV and a current of 200 μA. Currently, the maximum terminal voltage is limited to less than 4 MV. The shielding is sufficient for any monoenergetic source known. A diagram of the facility is shown in Figure 27. The most used part of the accelerator is the swinger and time-of-flight tunnel. The pulsing and bunching has a master frequency of 5 MHz for 200 ns between pulses. Beam pulse widths have measured full width at half maximum of 0.6 ns for both protons and deuteron beams. The frequency (f) can be reduced to f/2n, however this does come with the loss of half of the beam for each reduction. There are two ion sources that are available a Cesium Sputter source and a duoplasmatron with a sodium vapor ion exchange channel. For practical purposes only the proton and deuteron beams are of sufficient intensity for use in producing a monoenergetic neutron beam. The amount of beam on target pulsed and bunched at f/1 is normally 1 to 2 μA.

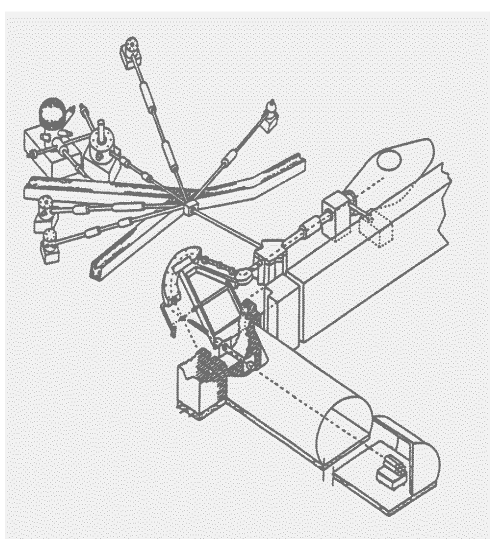

Figure 27: Ohio University Accelerator Lab showing the swinger and Time-of-Flight Tunnel.

Several reactions are useful for producing monoenergetic neutrons. A summary of these reactions is shown graphically in Figure 28 and are based on the calculations by Drosg[vi]. The yield of each reaction depends on the energy deposited in the target, the thicker the target, the greater the neutron yield and the wider the monoenergetic neutron peak. All of these reactions can be used at the OUAL. Safety regulations for the tritium gas targets limit the current to 1 μA. We do have solid tritium targets and a wobbler which can take a maximum of 5 mA of beam. The gas cells used for the majority of the reactions utilize a tungsten entrance foil. Extensive experience has shown that these foils will handle a maximum 10 μA of beam at 8 MeV. For ^{7}Li targets, we can also use 2.5 cm diameter targets with the wobbler a maximum current of 5 mA. The expected pulsed and bunch currents on target are 1- 2 μA much less than the maximum current that can be handled by any of the targets.

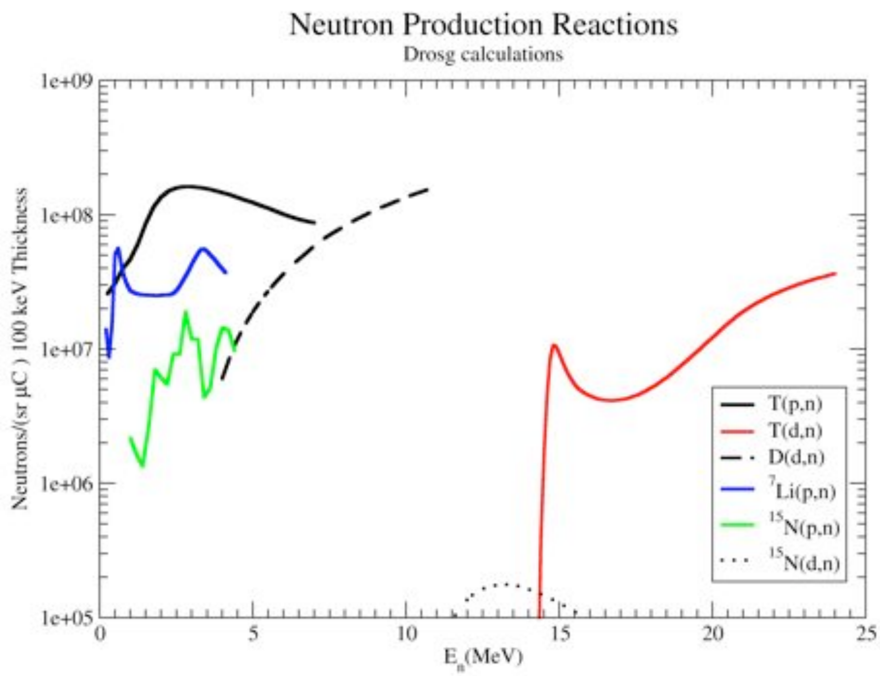

Figure 28: Monoenergetic neutron yield versus energy. Note: these calculations assume a 100 keV energy loss in the target.

Attention to the produced neutron spectrum is important when measuring fission cross sections of nuclei with a large thermal cross section. Some scattered neutrons will thermalize and return to the experimental area. The contribution of the thermal neutrons to the count rate can be determined by using a pulsed beam. A pulsed beam also allows the contribution of background reactions to be discriminated against. Examples of “monoenergetic” neutron spectra are shown in Figure 29. The peak to total neutron count is quite good for all of these reactions, however they are not good enough for a 1% measurement, which is motivation for using a pulsed beam rather than a D.C. beam.

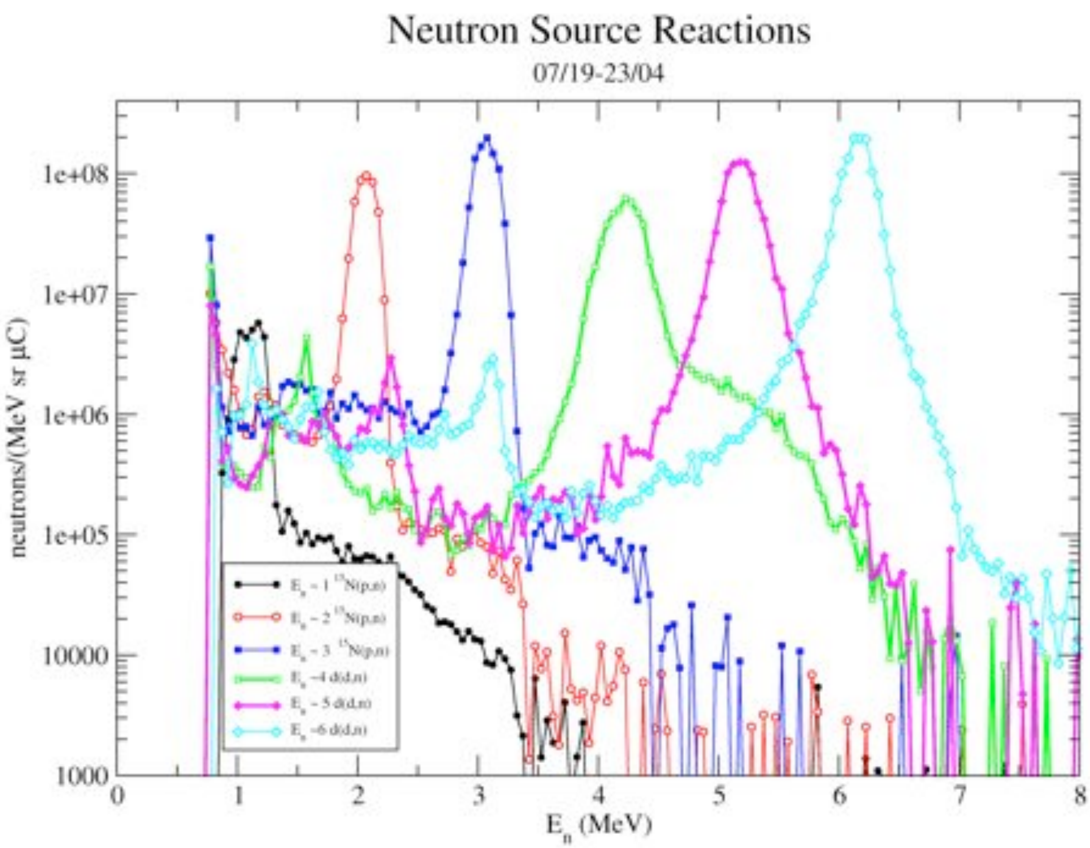

Figure 29: "Monoenergetic" Neutron Spectra showing the neutron backgrounds.

We have prepared for the TPC experiment by obtaining the needed permissions and licenses to work with actinide targets and the various gases to be used. The upper limit for the long-lived actinide fission foils is one gram. This should allow great flexibility in the targets used in the TPC. We also have a collection of fission foils which have been given to Ohio University by Argonne National Laboratory. We have a 50 microcurie Cf-252 source that is suitable for initial testing of the electronics of the TPC.

The working gasses of the TPC can be easily vented by existing vent systems.

Siting of the TPC at OUAL has two major options. The first option would be to place path TPC at 4 meters from the swinger axis in the time-of-flight tunnel. A second option would be to build a station in the large target room with a shorter distance.

The first option of the time-of-flight tunnel has many advantages. The beam swinger would allow flexibility in the angle used for the monoenergetic neutrons. Three nested sets of collimators were developed to allow reduction of the beam size entering into the TOF tunnel from 30 cm to 2 cm diameter. Previous work with fission chambers in the tunnel has shown a significant thermal background from both neutrons diffusing through the concrete and cinderblock wall and from the neutrons coming from the beam itself. A layer of borated polyethylene has been added to reduce the thermal neutron background. Due to the size of the TPC chamber, the closest place for it in the tunnel would be 4 meters from the center of the swinger axis. This is the best shielded place for working with the TPC. All services needed, such as power, vents, and internet connections, are already in place.

There are some drawbacks to working in the TOF tunnel. The opening to the TOF tunnel has a maximum opening of 73 cm. This should still allow installation of all of the equipment for the TPC. Initial calculation of the time to measure with thick 600 $\mu g/cm^2$ targets was estimated. The results of these calculations are shown in Table 5. For a reasonable cross section of 1 barn, the time for 10000 counts would be roughly 1 week for the maximum output of the $^{7}Li(p,n)$ reaction and 2 weeks for a region which is the non-peak neutron production energy. For the TPC at 0.5 meter, these times shrink by a factor of 64 from the increased solid angle and drop the time to two and six hours respectively.

Table 5:Measurement Time Estimate for a $^{235}U/^{238}U$ ratio experiment.

	^{238}U		^{235}U	
Atomic number	238	238	235	235
Target Area (cm^2)	19.6	19.6	19.6	
Area thickness ($\mu g/cm^2$)	600	600	600	600
Mass (g)	1.18E-02	1.18E-02	1.18E-02	1.18E-02
Number of Atoms	2.98E+19	2.98E+19	3.02E+19	3.02E+19
Proton Beam Energy (MeV)	2.3	3.5	2.3	3.5
Lithium Thickness (mg/cm^2)	0.7	0.7	0.7	0.7
Mean Neutron Energy (MeV)	0.528	1.784	0.528	1.784
Neutron Energy Width MeV	0.029	0.02	0.029	0.02
Flux neutrons at 1 cm ($/cm^2/\mu A$)	7.93E+05	2.51E+05	7.93E+05	2.51E+05
Beam current μA	2	2	2	2
Fission Cross Section (barns)	3.76E-04	0.482	1.137	1.259
Flight Path (cm)	200	200	200	200
Fission Fragments (hertz)	2.85E-04	1.16E-01	8.72-01	3.06E-01
Goal Number of Events	1.00E+04	1.00E+04	1.00E+04	1.00E+04
Time (hours)	97.4E+03	2.40E+01	3.18E00	9.07E00

We have begun work to design a 0.5 meter collimation setup. We have started with the previously used collimation for the H(n,n)H angular distribution measurements. The wobbler can be substituted for the gas cell if reactions using the solid tritium target or ^{7}Li targets are desired. The major job for MCNP calculation is to determine the amount of shielding needed to reduce the thermal neutron background in the TPC. We have three water filled neutron shields that may prove useful. Each shield has a bore of 14 cm through it with a height of 45.5 cm, a width of 46 cm and a length of 51 cm. A possible configuration is to place this shield directly over the gas cell region to reduce the emission at backward angles, greater than 45 degrees. We are currently putting geometry of the components of the gas cell and assembly into MCNP for calculation of the resulting neutron spectra. The 0.5 meter station can be located on the 45 degree right beam leg. The background from thermal neutrons can be evaluated using the current fission chambers before the installation of the TPC.

We are currently upgrading from a belt charging system to a pelletron charging system. This should improve the stability of the beam and the availability of the tandem. An upgrade that has been applied for previously is a Torvic Ion Source. This would improve the source output for proton and deuterons by at least a factor of ten. This would both decrease the counting time need by the same factor. This increased current may increase the flux from “white” source reaction enough to make them interesting for measurements with the TPC.

Ohio University Accelerator Laboratory has no direct funding for operation from either NSF or DOE. Thus funding for this beam time will have to be negotiated with Professor David Ingram Department Head and Professor Carl Brune Head of the INPP and the Chair o the Tandem Accelerator Lab. External student, postdocs and scientists can be trained as Accelerator Operators to reduce the impact of the run.

Facilities and Operation [LANL, LLNL, OU]

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.

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 experimental infrastructure will be partially provided by facilities currently at the LANSCE facility. A good working rapport has been 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

- Pu-239 safety basis for use in beam experiments was completed and first data was successfully collected at LANSCE during the last beam cycle. The operations of installing and monitoring the target was carried out without incident, resulting in high confidence that future Pu-239 measurements will not be hindered.
- LANSCE WNR construction was halted during the last quarter to insure maximum TPC beam time. The construction project is on schedule and will provide expanded and necessary floor space for this effort.

Livermore [LLNL]

There are numerous facilities at LLNL that are of interest to this project. The construction of ALEXIS, Accelerator at Livermore for EXperiments in Isotope Sciences, is still being considered. This facility will generate pseudo-monoenergetic neutrons up to 108 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.

TPC Laboratory Improvements

Expanded the TPC lab space at LLNL by 50%. Work on the lab infrastructure includes new A/C units, which slowed lab work on the TPC this quarter.

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 refurnished 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.

Hardware and Slow Control Improvements

New TPC hardware was implemented in the experimental setup at WNR in January 2012 to address issues identified in the previous quarter. A filter circuit, built to carefully control the high voltage settings of the MicroMegas, was integrated into the existing high-voltage system, allowing all high-voltage power supplies to be controlled remotely. The original design of this low-noise circuit ran on 9V batteries, which needed to be changed approximately every two days. In February, a second design (running on LEDs and solar cells) was shipped to LANL, which ran smoothly and required little to no maintenance by on-site personnel. The second MicroMegas filter circuit is shown in Figure 30.

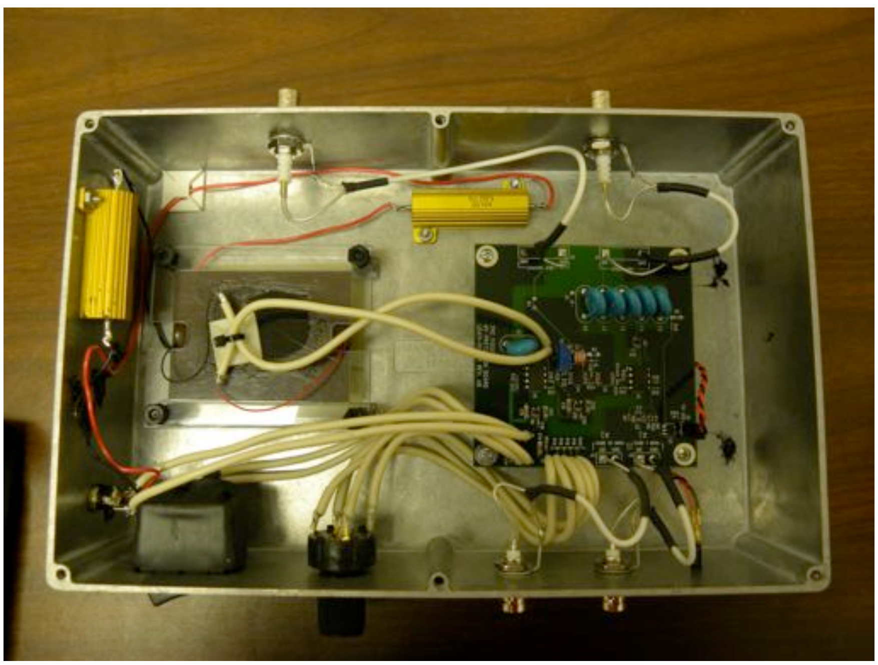

Figure 30: MicroMegas Filter Circuit, version 2.

The low voltage Power Distribution Unit (PDU, Figure 31) was also integrated into the TPC setup at WNR this quarter. The PDU controlled the clock, trigger, reset, and voltages for the digital bus boards and allowed remote users to shut down all low voltage power supplies, thereby placing the TPC into a safe, idle state that could be maintained indefinitely. New slow control monitors of the PDU state (on, off, tripped) were also implemented. Other slow controls monitors implemented in this quarter included: shutter status (open/closed); gas flow (on/off); beam intensity; and high voltage controls.

Figure 31: Low voltage Power Distribution Unit (PDU)

Plutonium Loading

Final approvals for loading Plutonium into the TPC and running in-beam were received in early February. The sample loading involves work in a customized radiological glove box (Figure 32) and the procedure was developed and practiced over several months using blank Carbon samples. The first TPC Pu-239 sample loading was successfully completed in February. The highly enriched sample had a total mass of 0.35 mg, and was electroplated onto a solid aluminum backing. The deposit was 2 cm in diameter, corresponding to a thickness of 111 μg/cm^2, and consistent with the samples that will be used for cross-section measurements. Figure 33 shows the Pu sample loaded into the TPC.

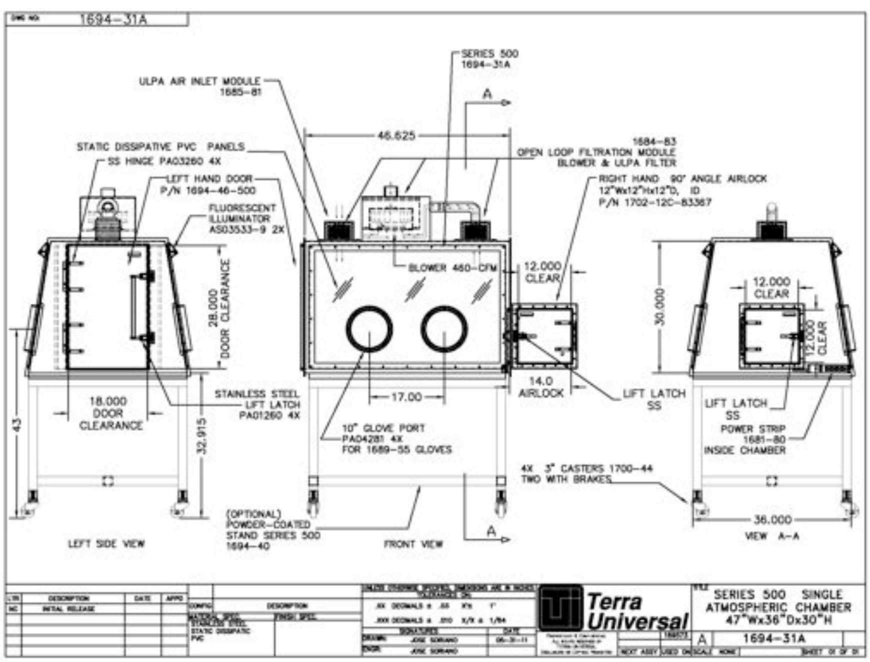

Figure 32: Glove box used for Pu loading at LANL.

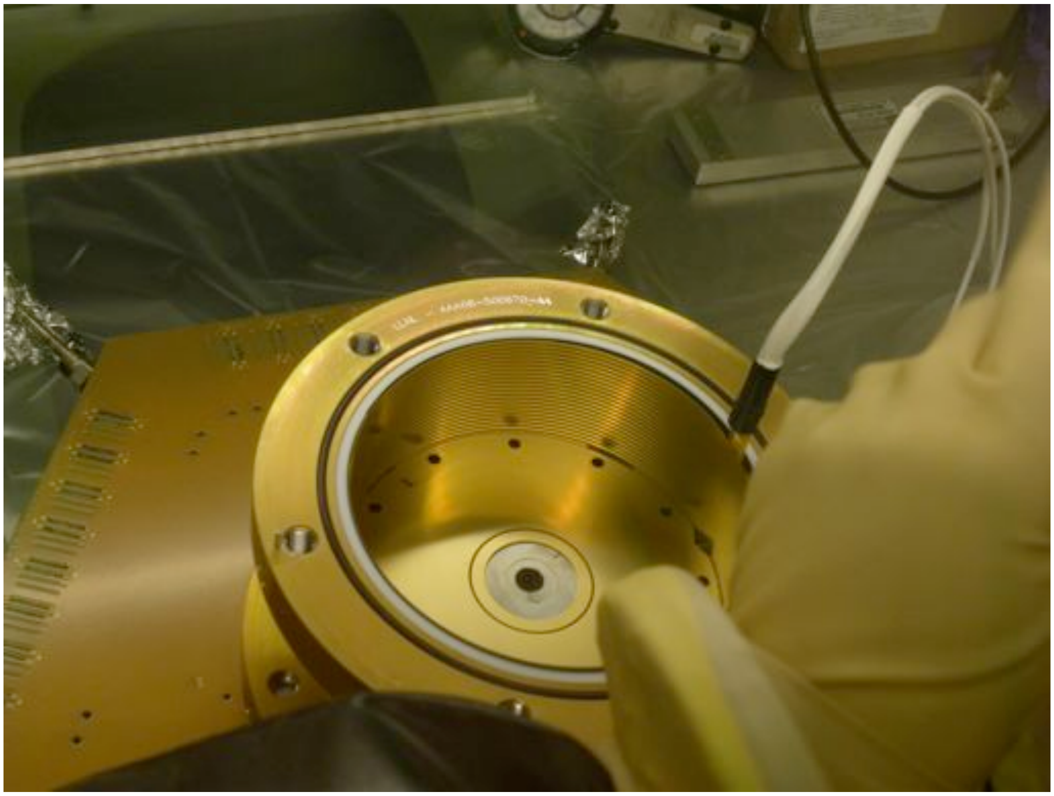

Figure 33: Pu-239 sample loaded into TPC.

Data Runs

The second half of the 2011-2012 LANSCE run cycle began in January. The WNR construction project was paused to allow for 24 hour beam operations on the 90L flight path. This flight path views the bare spallation target from a 90 degree angle relative to the proton beam axis, which is ideal for fission experiments since the flux is high in the 1-20 MeV range that is of particular interest for these experiments, and lower in the hundreds of MeV-range compared to the more forward flight paths at WNR, which helps reduce the experimental background levels. This is a relatively short flight path, with a nominal detector location of 10 meters from the neutron production target. The TPC took data 24/7 when beam is available, with an average live time of about 75% of the time. This data is with just 1/12 of the TPC or about 500 pads instrumented. This is valuable data that can be used to start turning up the analysis while the remainder of the electronics are finished.

The flight path sits directly against the Target 4 bulk shielding. The beam pipe is evacuated up to the shutter at the end of the bulk shielding, and the beam is then transported in air to the detector. The neutron flux at the detector location is shown in Figure 34.

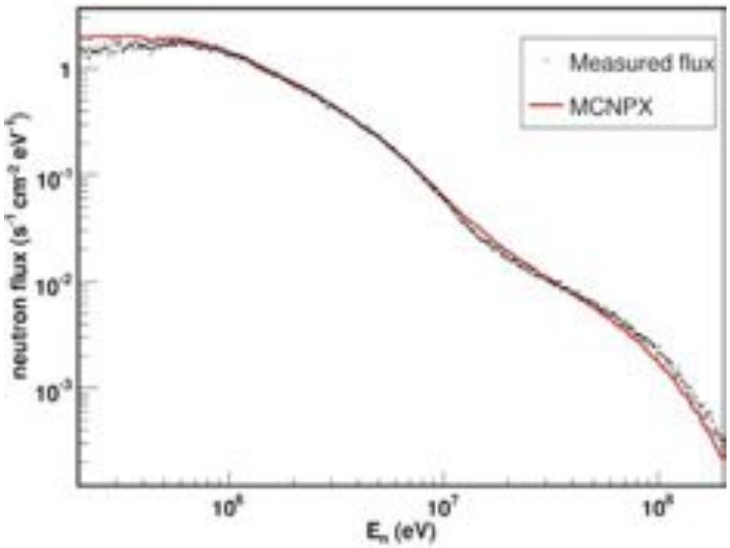

Figure 34: Measured (black) and calculated (red) neutron flux at 90L.

During the January maintenance period, a new U238/U235 mixed isotope target was loaded into the TPC (Figure 35). Beam experiments commenced January 12, running 24 hours per day until January 27. In early February the Pu-239 sample (see: Plutonium Loading, above) was loaded into the TPC. The TPC performed well, despite the high alpha decay rate of the Pu-239 sample (0.8 MBq). The high-rate (1 Tb/hour) data collected with low thresholds (to collect all alpha-particle tracks) will be very valuable when preparing for next run cycle's Pu-239 runs. 16 days of Pu-239 beam data was collected at LANSCE-WNR in February, before the facility entered the annual outage period February 28.

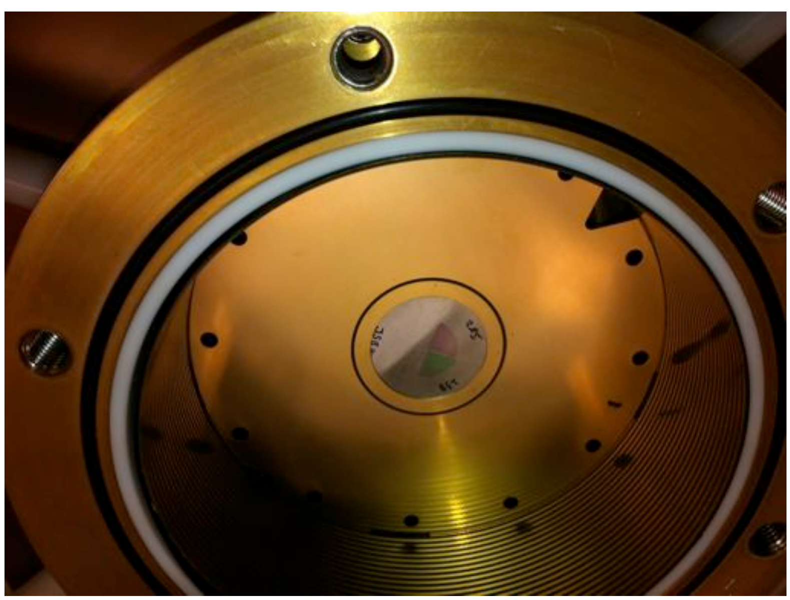

Figure 35: U235/U238 mixed isotope target, used in January 2012, loaded into TPC.

WNR Construction

The construction of a new building that will cover a large part of the WNR south yard resumed in March after a two-month hiatus (to allow for 24 hour beam operations). The building will be adjacent to the 90L flight path, and the entrance to 90L will be inside the new building (Figure 36). New work space will be available for the TPC project, which will lead to a reconfiguration of the currently used space.

The resumed construction is on-schedule to be completed at the end of May. The steel superstructure has been erected and work on the building roof is underway (Figure 37).

Figure 36: The WNR south yard after the concrete slab was poured, before a 2-month pause in construction.

Figure 37: The new WNR building on March 29, 2012.

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 duoplasmatron 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.

Tandem Operations

We have completed the conversion of our tandem into a pelletron. We anticipate on months testing before experiments resume.We have reached a terminal voltage of 4.0 MV with 75 PSI SF6 in the tandem. We will increase the SF6 pressure to 95 PSI to allow stable operation to higher voltages. We have 15 operators taking refresher training to comply with the new Ohio Department of Health rules for industrial accelerators. We have recently lost the facility chiller due to freezing the heat exchanger, repairs are expected to take at least 3 weeks.

H(n,n)H Scattering Experiment

We produced a 6LiCl target on a platinum backing and a covering of gold. This will be used for efficiency determination using the symmetric reaction 6Li+ 6Li. We have begun the setup of the Hydrogen scattering experiment. The 252Cf calibration work to achieve ~2% errors in the efficiency between 1 and 8 MeV is currently underway. We are continuing the preparation work to perform the measurement of H(n,n)H scattering at small neutron scattering angles by measurement of the scattered neutron.

Management

The NIFFTE university collaborators are funded directly by the Advanced Fuel Campaign of the FCT Program. The PI of this contract has reporting responsibilities directly to the Technical Point of Contact at INL. The laboratories are being funded directly by the FCT and ARC programs to not only participate but to provide guidance and project oversight, including reporting requirements within the DOE/NE management system.

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