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# Quarterly Technical Report, Fission Time Projection Chamber Project, January2012

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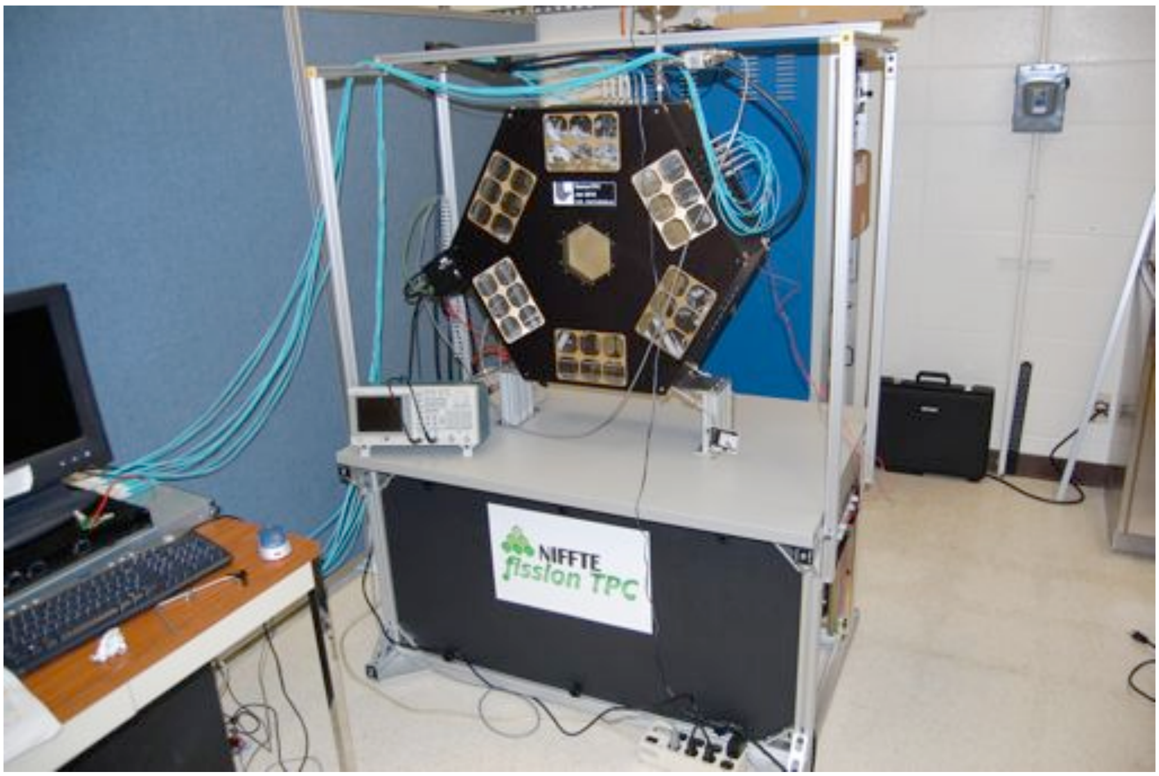
U.S. DEPARTMENT OF
ENERGY

January 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 $4\pi$-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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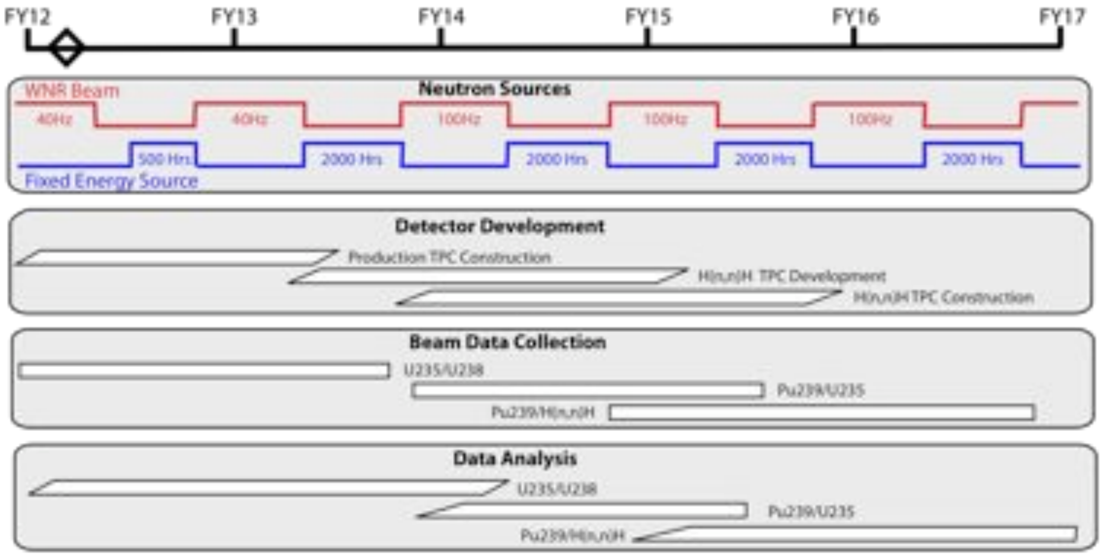
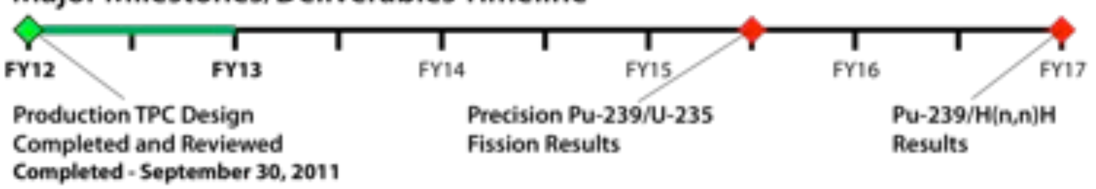
## TPC Project Timeline




## Major Milestones/Deliverables Timeline




## FY12 Supporting Milestones/Deliverables


## First Quarter Highlights FY12

- The latest TPC hardware have been integrated into the system on the 90L flight path. LANSCE beams were stable and high quality data from U-235/U-238 mixed targets were collected using a full sextant.
- All aspects of the NIFFTE software system performed well during data collection at LANL, monitoring on-site and off-site, data transfer and archive and reconstruction and analysis.
- 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 several options exist. Given the WNR construction delay and uncertainty, the level of effort for this will has been increased.

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## Table of Contents

# Principal Investigators

**Universities**

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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

- New pressure vessels have been manufactured and prepared for integration.
- A new remote controllable system has been implemented to control all the high voltages in the TPC volume and integrated into the slow control system.
- A modification to the preamplifier cards is being tested that will protect the delicate front-end amplifiers from sparks in the gas gap of the micromegas.
- An order for 60 new EtherDAQ cards was placed and will be tested in the next quarter.
- A working version of the high-speed cathode readout system has been tested and the results are being analyzed for time jitter and stability.
- The power distribution system for the cards and preamplifiers has been tested and installed on the TPC prototype in Los Alamos.

- Several thick targets were fabricated and shipped to Los Alamos for the data runs at LANSCE.
- The gas supply system has been successfully operating during active data collection at the 90L experimental hall at LANL. Minor issues were identified and will be addressed in the upcoming quarter.

## 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.

### *Pressure Vessel*

New pressure vessels were fabricated and were not machined exactly to specifications, and we simply shimmed them and that seems to work well.

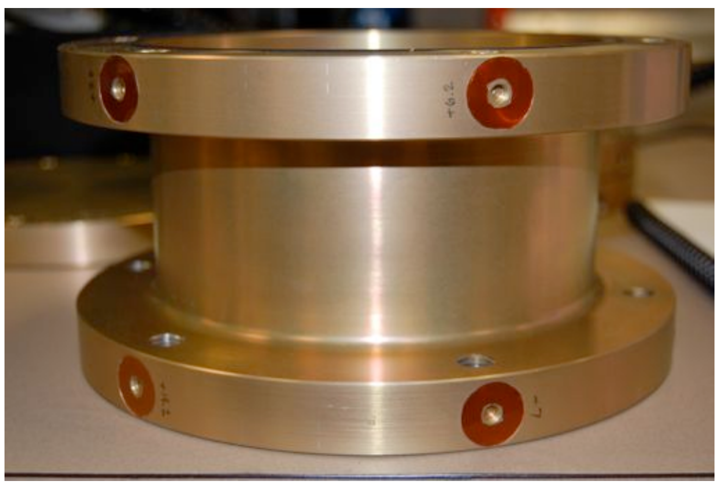

**Figure 1: Shims have been added to the TPC leg sockets to account for a manufacturing error.**

### *Cathode Pad plane*

A new pad pad plane and pressure vessel was installed into the LLNL TPC test stand to replace the parts sent to LANL for the 2011-2012 run cycles.

### *MicroMegas*

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 filtering batteries are drained too quickly (3 days). Work to fix that problem is underway.

**Figure 2: New high voltage system for the micromegas.**

### *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 cannot handle the power. The manufactures claimed that the fiber could pass the power, but we found that after a number of attempts it will simply not work. The problem appears to be that some of the laser power enters the cladding and the heating from that causes the fiber to crack, destroying it. In addition, we found that the divergence of the beam after passing through the glass rod and prisms put together by Blue Ridge optics is far from acceptable. We have decided to change the design to match closer to a proven design used in the STAR TPC experiment. The design for the new system is underway.

## 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 during LANSCE beam operations that the micromegas was not as stable as the operations at LLNL. Electron discharges between the mesh and the anode 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 substanially 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 tested and seems to work.  A second round of testing has started and will clear the way to produce a set of electronics that are resistant to spark damage.

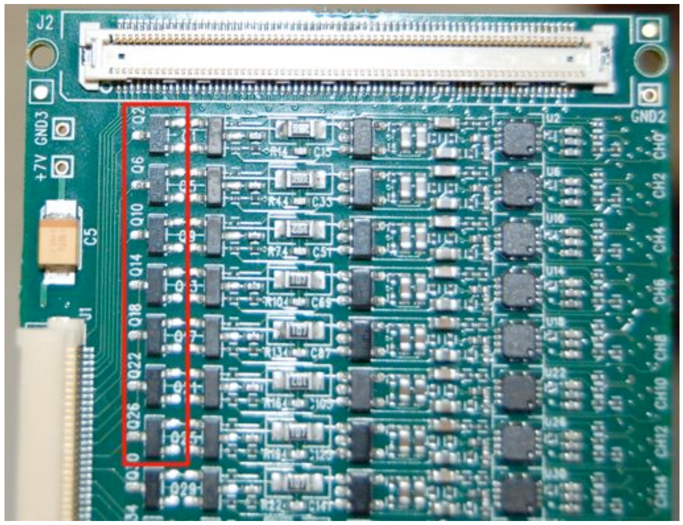

**Figure 3: The FETs that are damaged by sparking in the TPC.**

### *EtherDAQ Cards*

An order has been placed for 60 new EtherDAQ cards.  Delivery is expected in February.  Testing will also begin next quarter.

The EtherDAQ firmware has been improved to allow readout of the serial number from the Ethernet.  This allows auto-inventory of all the cards in the system.

### *HiSCaR*

The cathode of the TPC is being 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.  The work from here will be to combine these two efforts and drive down the system noise while keeping the speed.

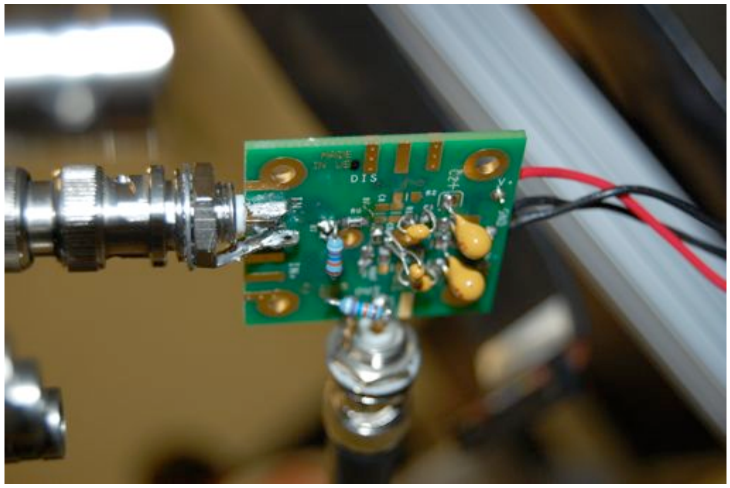

**Figure 4: Prototype preamp used on the TPC cathode.**

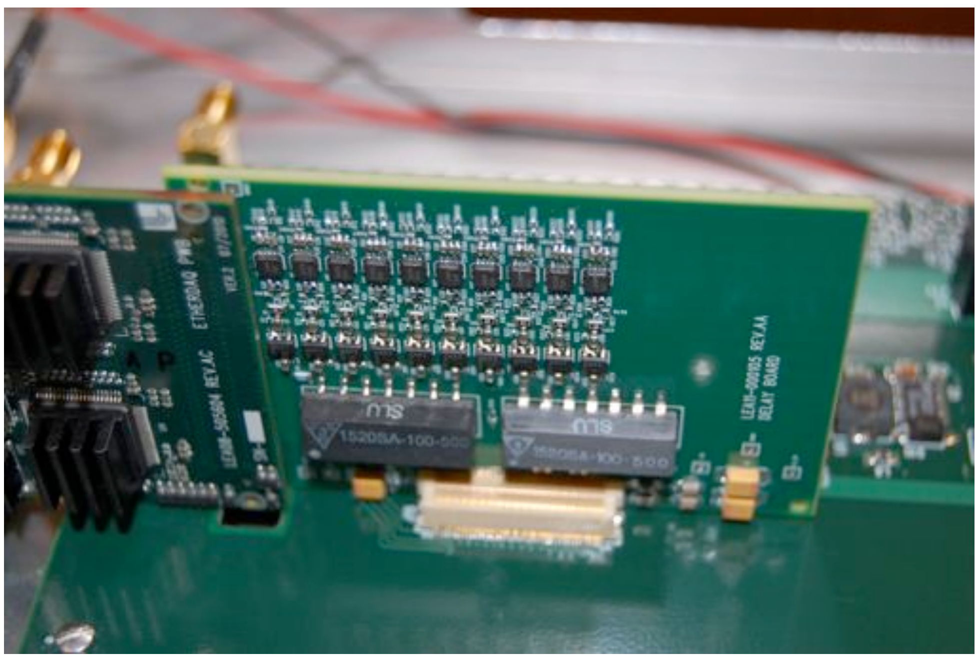

**Figure 5: Delay board used to get high speed timing with the TPC electronics need to get the signal readout on the TPC timebase.**

### *Power distribution*

The analog and digital electronics of the TPC consumes approximately 4 kW of power in operation.  In addition, the 192 sectors need careful clock distribution, triggering, and other signals distributed.  This will be accomplished with the power distribution rack.

Five power supplies feed power into the rack and the power is delivered into 12 digital bus boards and pad plane points are powered which in turn power the 192 sectors.

This rack monitors power conditions and will force automatic shutdown in the case of anomaly to prevent damage. The rack also has a remote shutdown so other interlocks can be implemented as well.

The main 25 MHz clock, from which the 31-62 MHz sample clock is derived, is also distributed in this rack. It is important that the clock be synchronized, in phase and maintains low jitter and noise. These requirements are designed into this rack. It also serves as a convenient point to collect the trigger in, busy, and trigger out.

**Figure 6: One of two PCBs that make up the power distribution rack. The lower PCB shown here which controls the analog is ready for testing. The upper PCB (not shown) is also complete and mounts above this board in the same rack.**

The power distribution boards were mounted in the chassis. The 24-volt part of the system was turned on for the first time and it communicated with the power supply to program it and it worked to interrupt the power in the case of an induced fault. A few problems were discovered with the reliability of the trip. A solution was designed and prototyped on the board and it appears to work.

The power and clock distribution system was completed for 2 channels and deployed at LANSCE (see Figure 7). This allows for operation of 32 frontend cards, and is a demonstration of what is needed to power the whole TPC. Simply scaling up this box will provide the 4 kW of power needed. It also has feature such as a remote shutoff and status for remote operation.

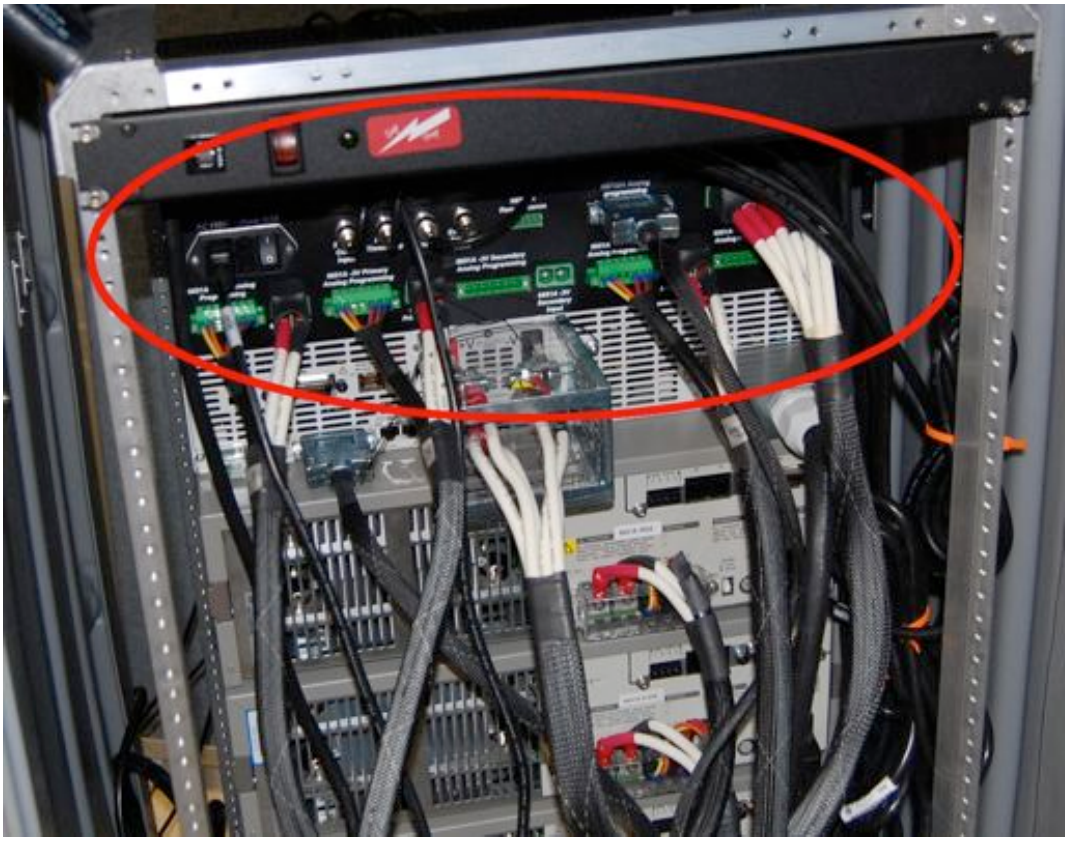

**Figure 7: The power and clock distribution system as installed at LANSCE.**

### *Digital Bus Board*

Two new digital bus boards were built for the operation at LANSCE this run cycle. These boards have the proper connectors to work with the power and clock distribution.

### *Preamp Test Stand*

The preamp test stand has been successfully installed at ISU in the Advanced Electronics clean room at the RISE Complex. Improvements to this lab include installation of a tornado air shower as well as anti-static protection materials including anti-static mats and grounding straps (see Figure 8). The system is under computer control and the software for testing all the cards is under development and expected to be completed and tested next quarter.

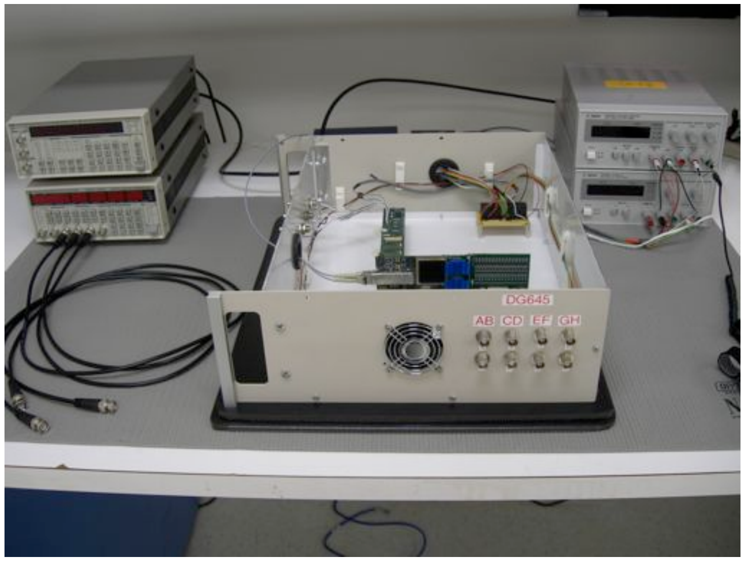


**Figure 8: The preamp test stand as of January 2012.**

### *Endurance Tests*

The preamp test stand was powered and had pulses from the pulse generator coming in on all inputs. Several minute-long runs and corresponding temperature readings were periodically taken over the course of the test. The temperature eventually stabilized around 26.7°C under nominal lab test conditions. A plot illustrating the behavior of channel 2 in the first event of every run is shown in Figure 9. From this plot, as well as additional analysis, continuous operation of a card seems to have a minimal effect on the pedestal and slope of the waveforms on any of the channels. Work to fully parameterize individual channel behavior is underway.

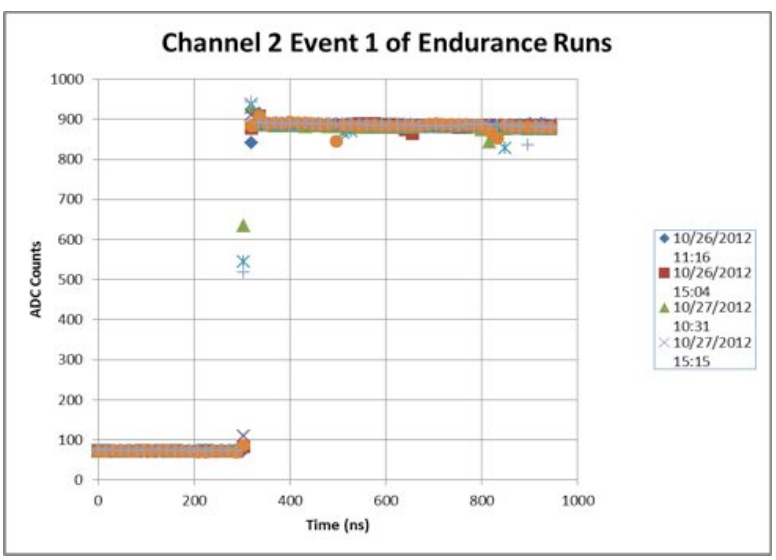


**Figure 9: Figures showing the data points from channel 2 in the first recorded event of the listed runs.**

# 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.

# 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 Preparation*

We prepared and shipped four $^{235}U/^{238}U$ targets to LANL. These mixed isotope targets consisted of specially shaped deposits of $UF_4$ on 81,000 μg/cm$^2$ Al (at the request of LANL). Two targets consisted of pie-shaped wedges of $^{235}U$ and $^{238}U$ diametrically opposite one another while the other two targets consisted of a half-circle deposit of $^{238}U$ with a pie shaped wedge of $^{235}U$ opposite to it. The $^{235}U$ deposits were 100-150 μg/cm$^2$ thick while the $^{238}U$ deposits were ~200-250 μg/cm$^2$.

Two multi-isotope ($^{235}U$, $^{238}U$) targets were also prepared. One target had 120° wedges separated by 1 mm (see Figure 10) while the other target had 90° wedges separated by 1 mm (see Figure 11). The targets were shipped to LANL in December.

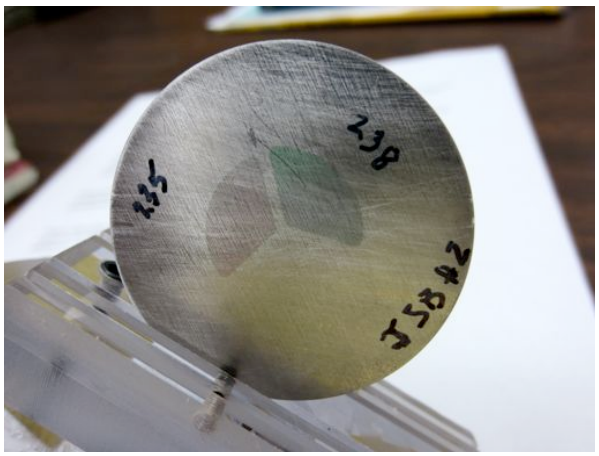


**Figure 10: A multi-isotope target consisting of U-238 and U-235 as 120° wedge shaped deposits.**

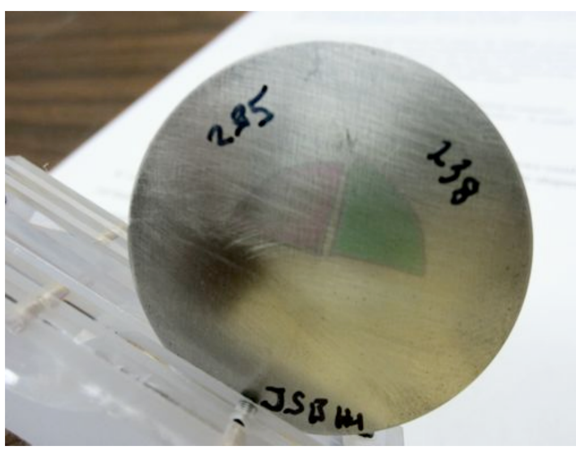


**Figure 11: A multi-isotope target consisting of U-238 and U-235 as 90° wedge shaped deposits.**

The construction of a time of flight/energy spectrometer for measuring fission fragment energy losses in future targets has also started this quarter.

# 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

- All aspects of the NIFFTE software system performed well during data collection at LANL, monitoring on-site and off-site, data transfer and archive and reconstruction and analysis.
- An initial study of using Radon gas to calibrate the TPC indicated that a higher activity sample and more data will be required to complete this calibration.

## 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 Software Update*

In this quarter, the online monitoring system for the detector performance and data quality checking has been updated. Several problems and issues have been addressed. The histograms were not drawn properly when started a new run during data taking due to the file pointer was out of scope (It takes ~30 seconds for the event builder to build first event from cdr file to be written to the disk). The issue had been fixed by idling the system to wait for the data to be written on the disk. The 2D histograms with polygonal bins were not saved to the root file successfully after the run finished (the root files will be used for archiving the history plots of data). It was found that the classImp should not be defined for the derived new root histogram type. The problem of redraw the 2D histograms during the run period was also be resolved.

New histograms had been added to enhance electronic status and performance monitoring and the data quality check in physics. The histograms are organized at different level to be shown in three catalogs in the MIDAS webpage.

- At the signal level, it checks the raw signal from the waveforms, which is the most direct and fast way to check the gain, pedestal and noise of the electronics.
- At the digit level, it checks the energy deposition in an ADC value of reconstructed digits from the signal waveforms and the number of digits per event, which will give a rough and first glance of the identifying and separation of different particles in the detector.
- At the track level, the full reconstruction of the track finding and fitting are performed to reconstruct the particle tracks in TPC which can be used to investigate the global performance of the TPC and data quality.

## 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.

### *Pad Gain Matching with Radon Gas Calibration*

Understanding the relative gain of each pad in the TPC detector is important for determining the amount of energy deposited in various parts of the active volume of the detector. The gain between pads can vary as a result of slight differences in geometry, defects in materials, and so on; these sorts of variations cannot be corrected for via pulser calibration like the pad electronics. A typical alpha calibration source is point-like and deposits different amounts of energy in different parts of the detector as the emitted particles travel outward. An example using beam data is shown in Figure 12. Notice how not only does the accumulated ADC value decrease as the events move away from the target region but there are also pad-to-pad variations in regions which should be similar.)

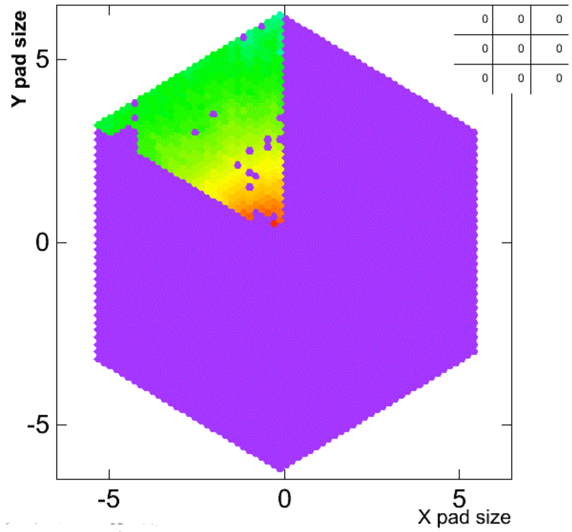


**Figure 12: Accumulated ADC for the active region of the TPC from neutron beam data (Run #400000689). Color denotes the sum with red being the largest and green being the smallest.**

An analysis involving a point source is heavily dependent upon a very accurate simulation and source placement. An alternate approach is to use a radioactive gas that fills the detector volume uniformly and provides essentially uniform amounts of energy deposition throughout the detector. Radon-220 gas from thorite was flowed into the detector and several data collection runs were performed. A 1.25-hour long run under optimal conditions was chosen for analysis. The Rn-220 has a half-life of 56 seconds and the decay chain emits two alpha particles with energies of 6.288 and 6.778 MeV. These alpha particles were observed over the course of the run with approximately 2600 reconstructed tracks. The two alpha particle energies are similar enough that they appear as one peak when the total energy for each event is plotted. Track length versus energy of the event shows clustering around 1800 ADC units and 4.5 cm in the 222Rn runs, which is compatible with results obtained for the 252Cf runs. The original concept was that an examination of the ADC spectrum for each individual pad would reveal a common feature (i.e. maximum energy deposition edge) that could be used to gain-match all of the pads. However, the amount of charge detected by each individual pad making up each track tended to be small. The statistics in the 1.25-hour run were not large enough to allow for a meaningful comparison of each pad's gain.

There are ideas that will be implemented after the current data collection period to increase the statistics. A new Rn-220 source has been produced with roughly10 times the activity. Also, even longer runs can be taken. An estimate of the data collection time required for acceptable statistics is underway based on the data collected previously.

Another simpler approach is being pursued which utilizes only the number of counts in each pad rather than the ADC distribution. This technique was utilized in previous TPC experiments (NA49) to perform initial gain matching. However, background count rate must also be taken into account. Once an appropriate background run is identified (i.e. one with the same gas pressure and voltage settings as a high quality radon run), a count rate comparison can be made. This method should require a smaller amount of collected events and so may yield acceptable results in less time.

### *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.

### *Slow Control System Updates*

Continuous work during the past quarter has been done on the slow control system as it was deployed and brought into operation. The primary instrument used was a Keithley 2701 Data Acquisition System with a Keithley 7710 multiplexer module. In addition a Fluke Blackstack temperature readout system remains the instrument of choice for monitoring the temperatures of the TPC itself. The Keithley is communicated with directly via Ethernet and has shown to be extremely flexible. The Blackstack requires an IEEE-488 (GPIB) to Ethernet adapter, but has worked well during the past quarter. Among our accomplishments were:

- Researched how to add gas pressure monitoring to slow control readout at a sufficient precision for the TPC which will use existing high precision sensors.

- Researched how to add controls for the Low Voltage (LV) system so that the LV can be turned off or on as required.
- Obtained access to a special welder for making thermocouple joints at ACU so that TCs can be built to custom lengths at low cost.
- Prepared for a member of the ACU group to be at LANL to commission parts of the NIFFTE slow control system not yet installed, while software aspects would be conducted from ACU remotely.
- Continued testing and code development for the slow control software and its interface to MIDAS.
- Integrated the high accuracy TPC measurement system into the slow controls.
- Installed thermistors on the TPC and around 90L.
- TPC HV supplies were connected to the DAQ computer and placed under MIDAS control. Control now can be local or remote.
- The TPC HV control software was updated to tolerate rare voltage read-back errors without triggering undesired ramping.
- TPC pressure changes recorded by the slow control system were investigated to understand what actually was happening. The variations appeared to be related to temperature changes of the TPC vessel caused by air conditioning cycling.

As the above accomplishments were made, plans were made for modifications to the slow control system in January, 2012. While what was in operation during this past data run was sufficient, we want to improve on the system's ability to detect abnormalities and complete automatic shutdowns of various systems without operator assistance. Then the person taking remote shifts can study any anomalous events and decide on the proper action to take.

The slow control database has been updated with the development and measurement output of the slow control system. Three tables have been added in the NiffteDAQdb for high voltage, TPC gas pressure and TPC inner temperature measurements. The MIDAS frontend program to record that information has been modified and updated to store the information into online database periodically.

Overall the slow control system has functioned as expected and no significant problems are foreseen when the full TPC is instrumented. In particular the Keithley system and Fluke Blackstack have worked well for the purposes they have been adapted to accomplish. Work will continue on making data available for the people on shift to evaluate the systems being monitored to avoid operating conditions that could prove to be detrimental to the TPC.

# 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

- Detailed simulations of the electron drift have been carried out this quarter to insure complete understanding of the features seen in the waveforms measured in the TPC.

### *GARFIELD Simulations*

A particular type of track artifact has been identified in the Fission TPC for fission fragments that is not present for lighter particles such as alphas or protons. It is better characterized in Figure 13, where the amount of charge collected on a pad from a single hypothetical track is shown for both an ideal simulation (roughly constant collection rate) and for an actual fission fragment event track, where a much slower collection rate occurs for the farthest portion of the track (circled in red). This "ghost tail" effect has a tendency to bend the part of the track farthest away from the pad plane (where the drifting electrons are collected) since the Z position is calculated by the arrival time of the electrons.

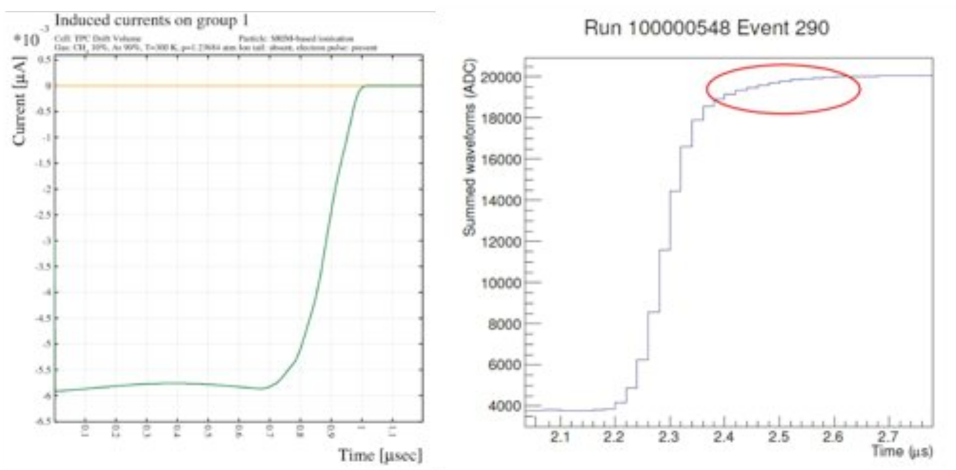


**Figure 13: Charge collected on pad from a hypothetical Ti-84 fission fragment track over time. At left is a simulation with no charge cloud effects, at right is actual data from the TPC. Note the slow final rise rate as compared to simulation.**

The leading hypothesis to explain this effect is the much larger number of electron-ion pairs generated by fission fragments as they travel through the detector volume. As can be seen in Figure 14, a typical fragment produces ~10 times as many ions as an alpha over a track length 25% as long, resulting in a significantly higher charge density of ions. This charge cloud could potentially affect the drifting electrons, effectively shielding them from the external force generated by the field cage.

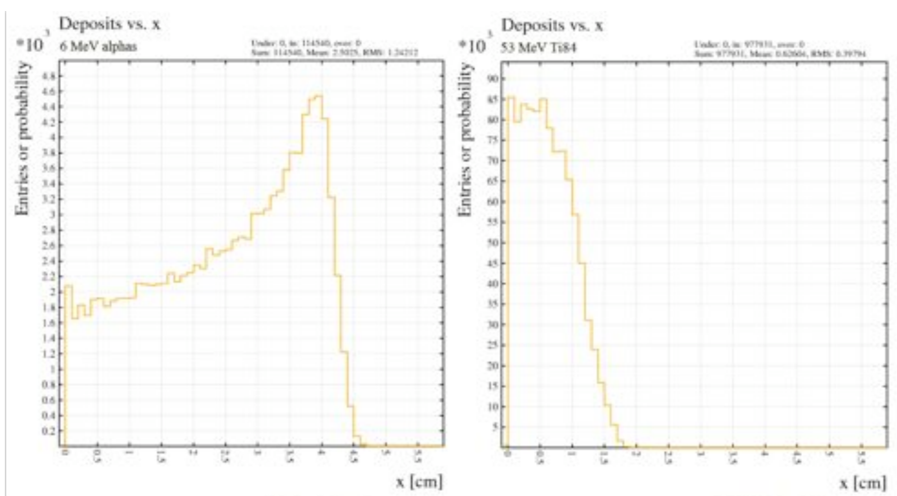


**Figure 14: Electron-ion pairs generated per cm for a single track. The Bragg peak is clearly identifiable at the end of the track (x ~ 4cm) for alphas at left, but occurs immediately for Ti-84 fragments at right, which have a smaller range due to greater energy loss rate.**

To attempt to recreate this effect, simulations were run in GARFIELD, a detailed simulation program for gaseous detectors. A simple model consisting of two 8cm x 8cm planes, one grounded and the other at -840V, were placed 5.5cm apart and the central region filled with P10 gas. Alpha and Ti-84 fission fragments were then simulated traveling from one plane to the other, representing particles emitted from the target in the TPC. GARFIELD is capable of generating three-dimensional field maps and interfaces to the Magboltz and SRIM programs for detailed calculation of electron transport properties in gas.

Once the ideal (no charge cloud present) scenarios were modeled, the addition of a simplified charge cloud was added to the geometry. This was represented as a dielectric cylinder 0.1cm in diameter and 1cm long, roughly representing the region of electron-ion pair generation. A charge of $3.2 \times 10^{-13}$ Coulombs was applied to this cylinder, representing the total number of pairs generated by the full energy of the fragment.

Unfortunately, it was quickly identified that GARFIELD assumes that all defined shapes are solid, and particles are not tracked through them, as can be seen in Figure 15. It was confirmed that the neBEM finite element program built into GARFIELD currently does not support charge cloud representations, although they are working on it as a high priority.

GARFIELD is also capable of importing field maps from other tools such as Maxwell. Maxwell is a finite-element program capable of detailed electrostatic calculations. The same geometry as defined in GARFIELD was implemented in Maxwell, resulting in the field map shown in Figure 16. The charge cloud region is barely visible in this figure as a light region near the bottom plane. This field map is currently in the process of being imported into GARFIELD, where it will be used to track electron drift and measure the electron arrival times to determine if the charge cloud geometry is the cause of waveform variations that suggest later charge arrival times than nominally expected.

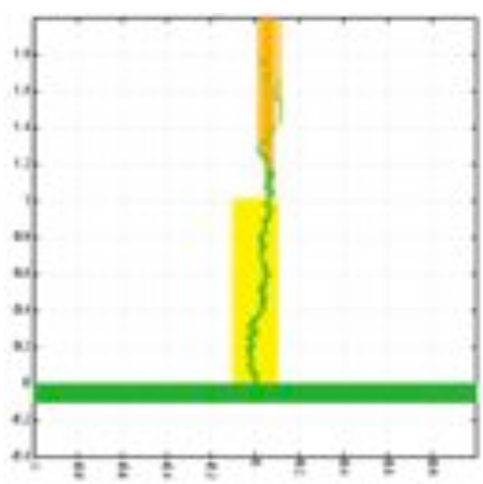

**Figure 15: GARFIELD simulation of Ti-84 fission fragment interactions. The fission fragment is traveling upward in this geometry. Green circles represent electron-ion pair generation points, and the orange lines are the resulting drift tracks of the electrons. The yellow region represents the charge cloud region of ions; note that no electron drift tracks are traced out of that area.**

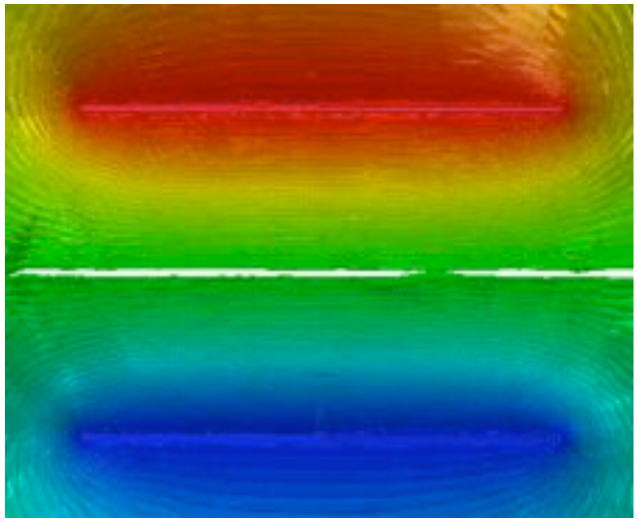

**Figure 16: MAXWELL representation of an electric field without field cage contributions. The ion charge cloud region is barely visible as a lighter region above the lower pad plane.**

# 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*

- An initial analysis of the Cf-252 data is complete and the alpha/SF branching ratio was measured to within 1% of the accepted value.
- Analysis of LANL beam-target data was started and is ongoing. Initial results indicate clear separation of proton, alpha and fragment tracks.

### *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 1/12$^{th}$ 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.

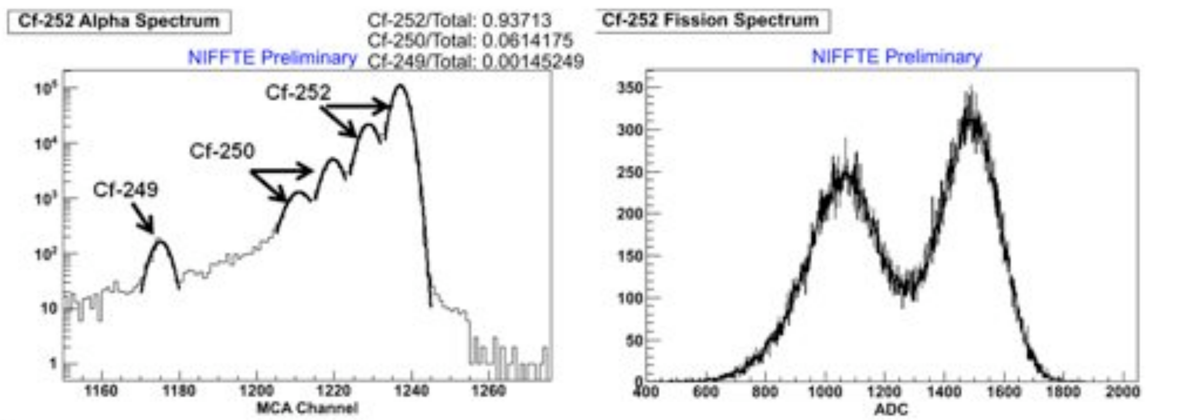


**Figure 17: The alpha spectrum of the Cf-252 button source as measured with a silicon diode detector. The plot on the left shows the alpha spectrum, the y-axis is in logarithmic scale. The plot on the right is the fission spectrum. The expected major contaminates were Cf-249 with an alpha energy of 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.

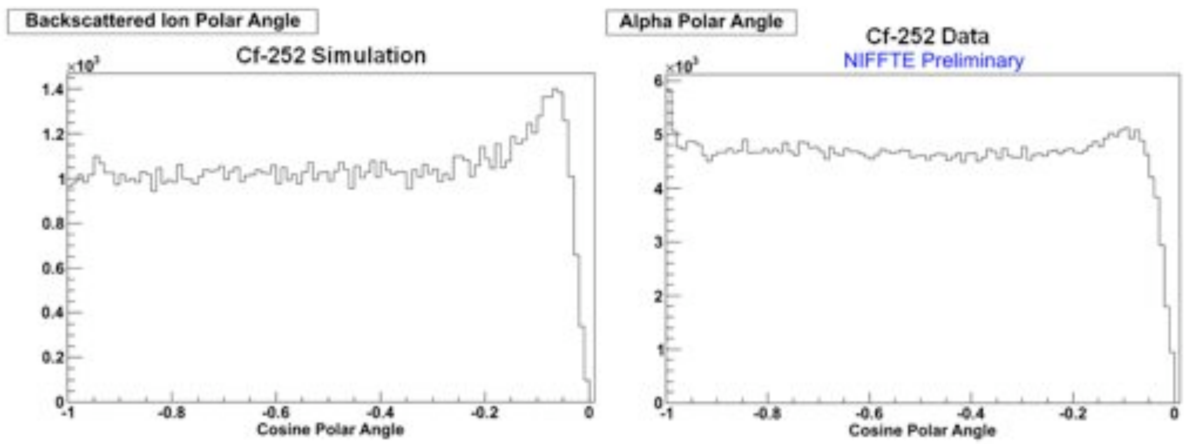


**Figure 18: The left plot is a simulation of the Polar angle distribution of the alpha particles that have either been transmitted directly through a 100 μg/cm² gold covering or backscattered off a thick platinum backing and then transmitted through the thin gold covering. The simulation was based on 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.

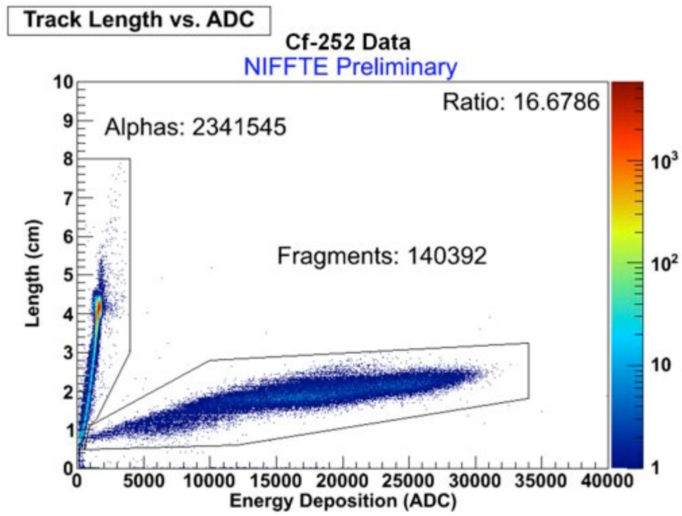


**Figure 19: The track length vs. the ADC of particle tracks in the TPC. The color scale is logarithmic. The band on the left at low energy with long track lengths are alpha particles, while the high energy short tracks are fission fragments. The number of fission fragments and alpha particles are based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

## *Analysis of U-238 target trial runs*

During the first week of official remote monitoring of the TPC, data analysis was performed as soon as the new data became available. The reconstruction software proved to be efficient and the analysis could provide essential feedback for the ongoing experiment. In fact, two major issues were identified in almost real time and therefore vastly improved the data quality for the rest of the run cycle.

Immediately after a new target was swapped into the TPC, a sudden disappearance of high energy events was observed. After the first trial runs with the U-238 target from last run cycle, the target was changed to a new mixed U-235/U-238 target with aluminum backing.  Figure 20 shows histograms of the total ADC recorded per event from one run before the switch and one run after.

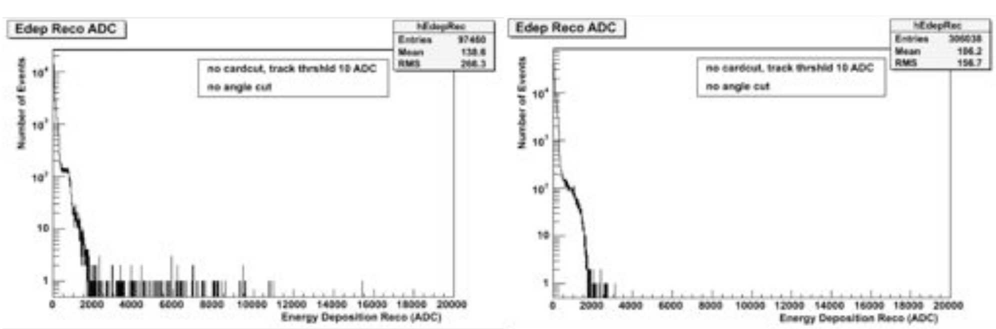


**Figure 20: Energy deposition distributions for runs #260 before the target change (left) and #273 after the target change (right). No higher energy entries are visible after the change.**

Length versus ADC plots (Figure 21 below) did not have entries in the higher ADC range characteristic for fission fragments.

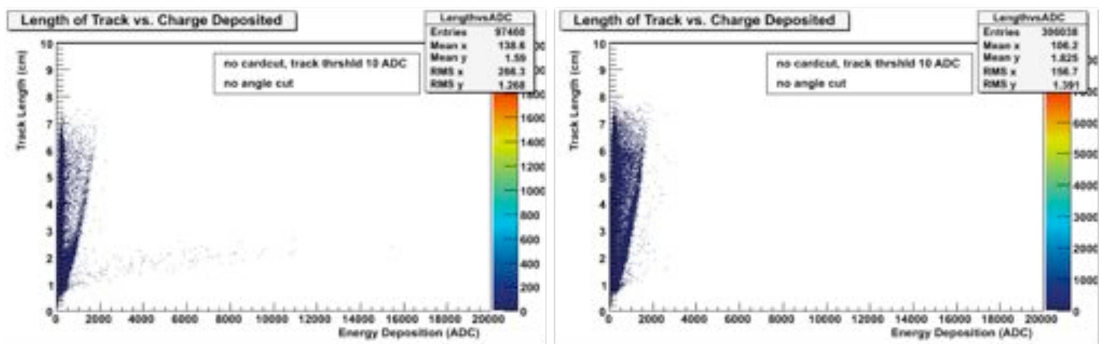


**Figure 21: Length versus ADC plots for runs #260 before the target change (left) and #273 after the target change (right). No fragments are visible after the change.**

These analyses clearly showed that there were no fission fragments reaching the detector, so it was determined that the most likely cause was that the target orientation was backwards, with the thick aluminum backing facing the active area of the TPC. The TPC was opened to confirm this mistake, and the target was flipped for subsequent runs.

After flipping the target, higher energy entries could be observed in the energy distribution plot (see Figure 22), but a new problem was observed in the Length versus ADC plot (Figure 23). Compared to a "normal" Length vs. ADC plot (see Figure 21), the lengths of tracks in Figure 23 are shortened.

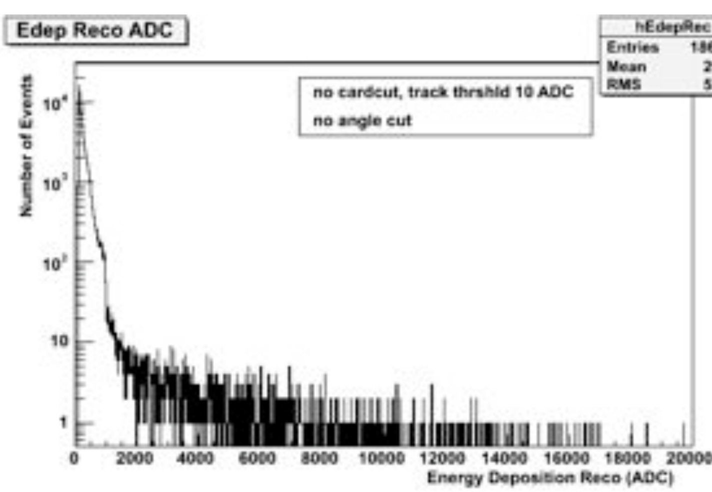


**Figure 22:e energy distribution for run #365 after flipping the target. Higher energies are now visible.**

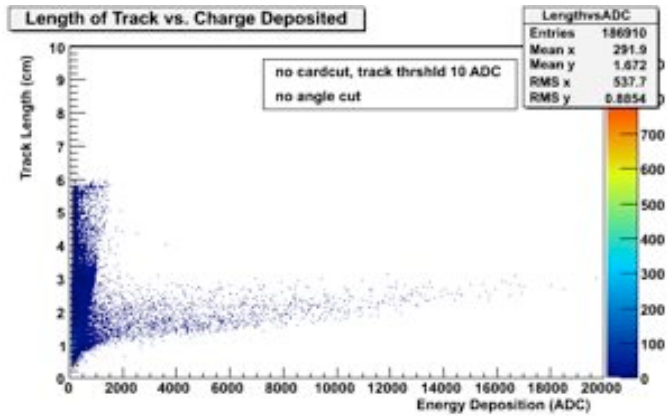


**Figure 23:. Length versus ADC plot for run #365 after flipping the target. Fragments are now visible, but a problem with alpha track length is obvious.**

A further investigation of the track length problem included the analysis of the vertex or start position of tracks (see Figure 24) and of the track length versus angle distribution, as can be seen in Figure 25. The geometric effects (pointing out the pad structure) in the vertex plot, the very short track lengths and the extremely non-flat distribution of track length over the polar angle indicated a clock synchronization problem of the individual sectors (cards) of the detector. In the lengths versus angle plot on can see that near cos(θ) = 0 (perpendicular to the beam = parallel to the detector plane) the longest tracks present are only 2 cm, which is about the long diagonal length of single parallelogram shaped sector on the pad plane. A typical alpha particle track should be significantly longer than 2 cm. The longer tracks towards cos(θ) = 1 (parallel to the beam axis) are present because some tracks can be completely contained over a single sector on the pad plane. Runs up to # 380 after the target flip did not have proper synchronization, making them test runs.

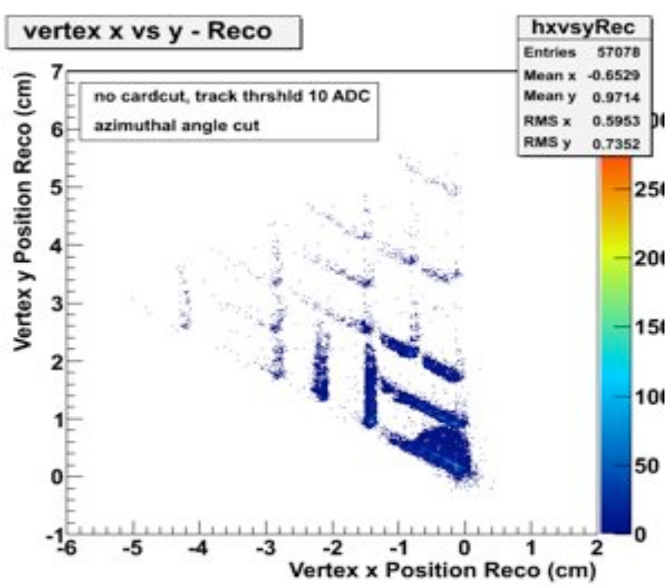


**Figure 24:Vertex plot for run #365 after flipping the target. The geometric mapping of the pad plane in the vertex plot also indicates a problem with synchronization.**

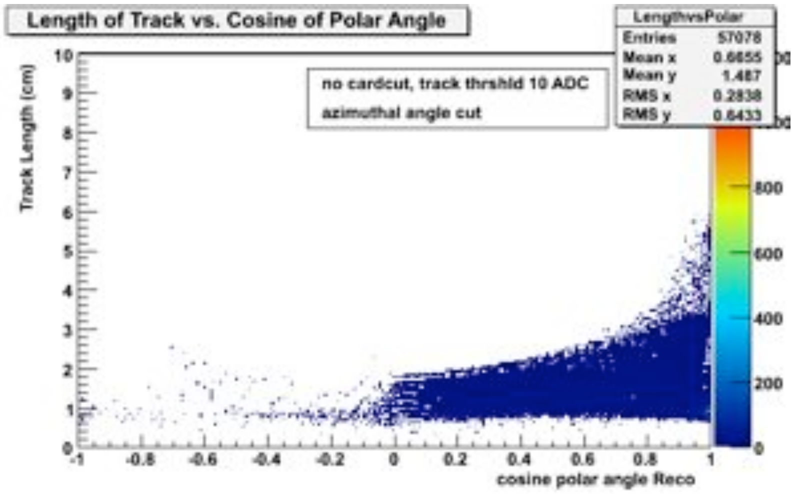


**Figure 25: Length versus polar angle for run #365 after flipping the target. The short tracks parallel and the long tracks perpendicular to the detector plane indicate a problem with the synchronization.**

After run number 380, the cards were synched properly and prompt analysis confirmed that the detector was functioning as expected. Overall it could be shown how valuable fast and reliable analysis procedures are for the performance of the experiment. The reconstruction and analysis chain works smoothly and there is enough knowledge within the team to correct experimental issues on the go.

Once the detector issues noted above were addressed, the data quality was much improved. Figure 26 shows a typical track length versus track ADC plot for tracks taken with a neutron beam incident on a combined $^{235}U/^{238}U$ target. Figure 26 also shows the same plot but zoomed in to reveal the structure in the lower energy range. There are many interesting features in these plots that will need further study, but some preliminary interpretations can be made.

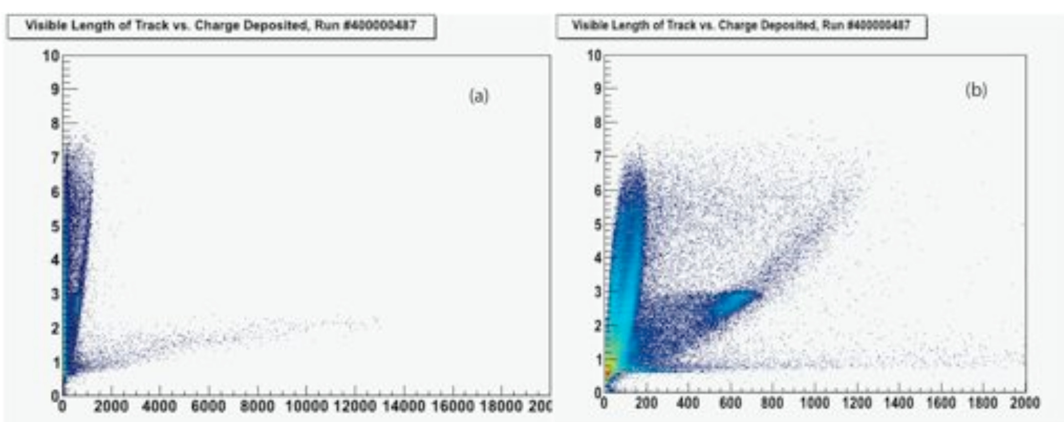


**Figure 26: Length versus ADC counts for a typical run (left) and zoomed in to reveal details in low energy range (right).**

The tracks are naturally divided in three distinct energy and length ranges. The band of short, high-energy tracks (ADC > ~1500) are consistent with fission fragments. The energy range from ~200 to ~1000 ADC counts are consistent with alpha particles, and a clear peak near ADC = 600 and Length = 2.5 cm is observed. The very low energy tracks (ADC < 200) are consistent with protons. The proton band is further divided into two distinct regions, and preliminary analysis indicates that these are indeed both protons. The higher energy proton tracks are those for which the Bragg peak is observed in the detector volume, whereas the Bragg peak for the lower energy tracks occurs outside the detector volume.

# 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

- Feasibility studies were completed for TPC data collection at the Ohio University Accelerator Laboratory. Capability comparisons with other laboratories were also made to fully delineate the possible options.

## 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 $^{6}Li(n,\alpha)^{3}H$, $^{10}B(n,\alpha)^{7}Li$ 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 27 shows the ENDF/B-VII.0 Pu-239 and U-235 cross sections with potentially useful energy points for measurements.

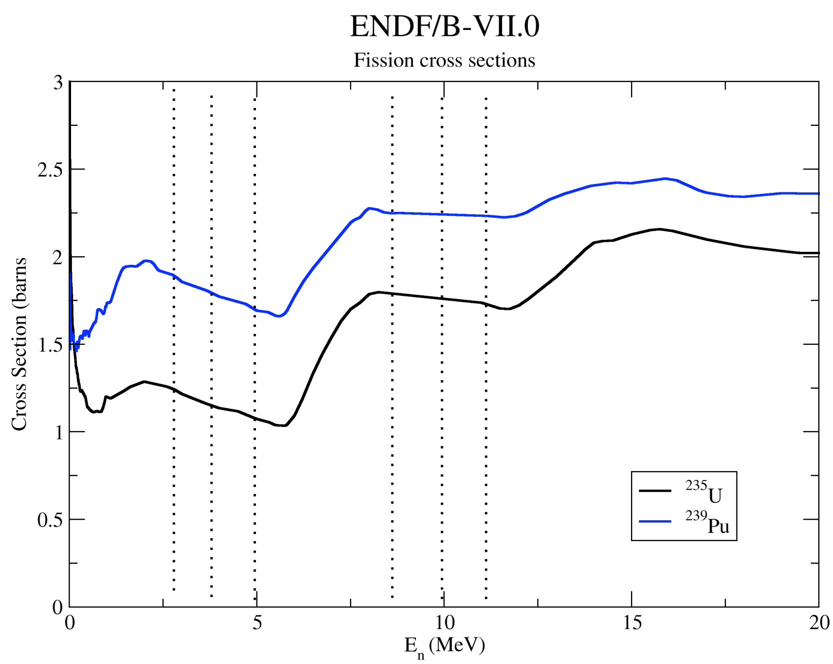


**Figure 27: ENDF Evaluations of the $^{235}U$ and $^{239}Pu$ fission cross sections. Regions where monoenergetic ratio measurements would be useful are shown by the dotted lines.**

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 1: 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 1, 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 $1 \times 10^6$ 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 28). 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 28. 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.

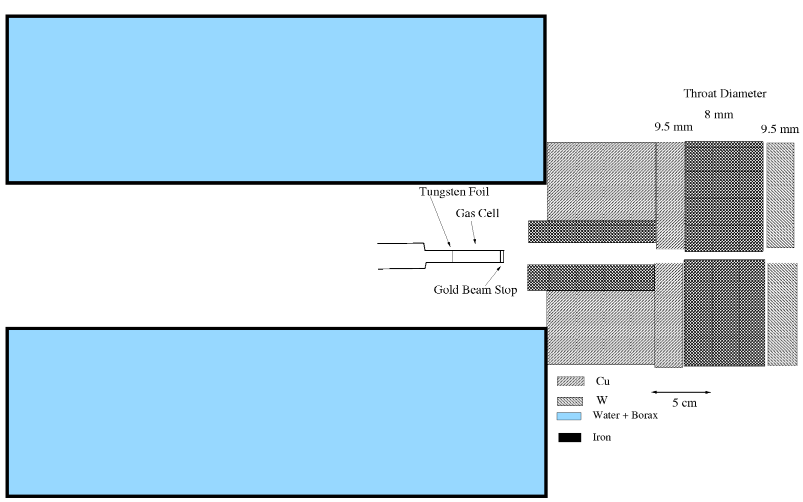


**Figure 28: The proposed collimation and shielding at OUAL for the TPC at 0.5 meters from the source reaction. Additional shielding will be added following planned MCNP calculations.**

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 29.

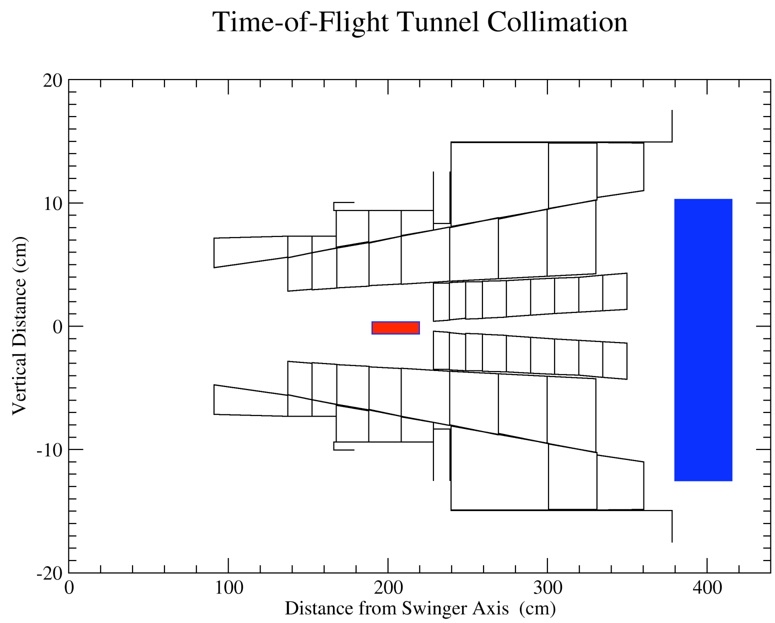


**Figure 29: Tunnel Collimation set shown for all collimators in place. The outer set is high-density nylon and the inner two are fabricated from polyethylene. For normal operation the gas cell would be located at the axis. If a beam line extension with a steering quadrupole is installed a gas cell (red) 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 30. 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.

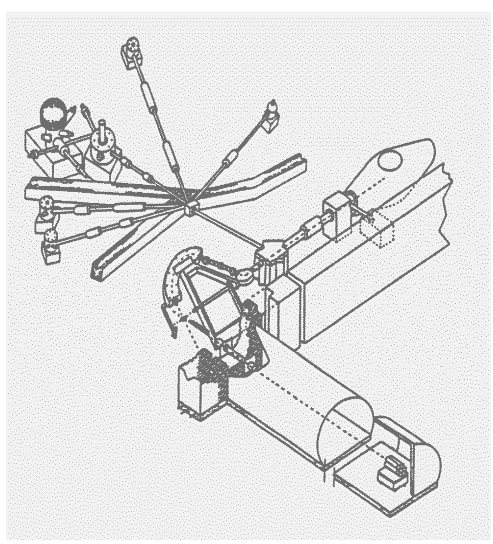

**Figure 30: Ohio University Accelerator Lab showing the swinger and Time-of-Flight Tunnel.**

Several reactions are useful for producing monoenergetic neutrons. A summary of these reactions is shown graphically in Figure 31 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.

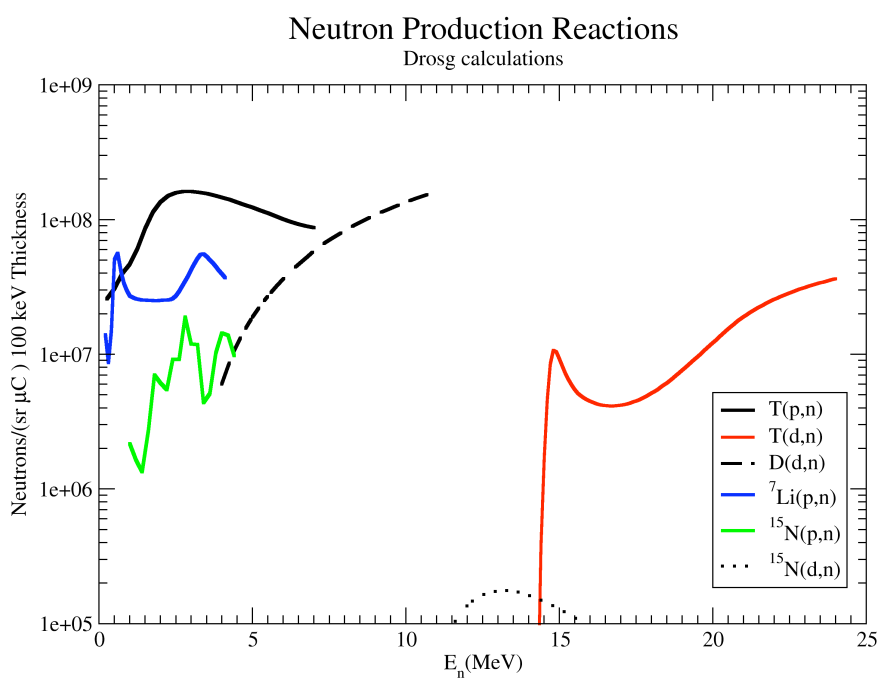


**Figure 31: Monoenergetic neutron yield versus energy. Note: these calculations assume a 100 keV energy loss in the target.**

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 32. 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.

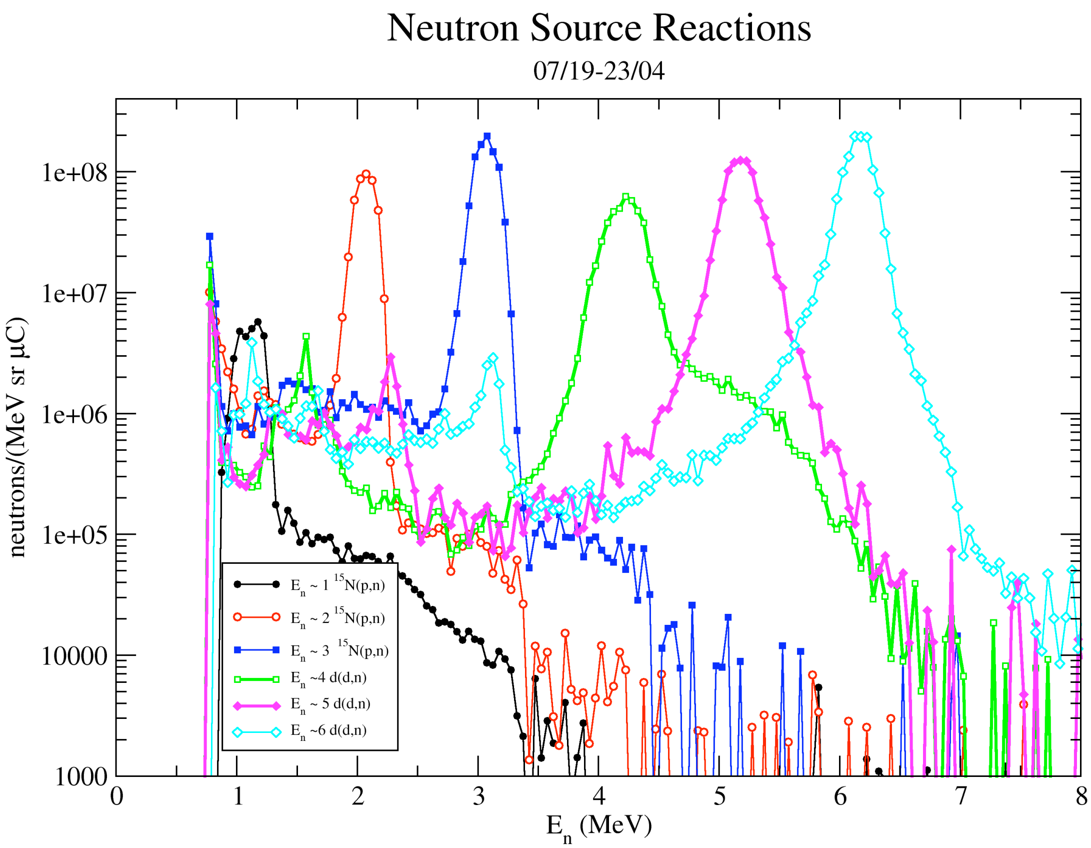


**Figure 32: "Monoenergetic" Neutron Spectra showing the neutron backgrounds.**

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 2. For a reasonable cross section of 1 barn, the time for 10000 counts would be roughly 1 week for the maximum output of the $^7Li(p,n)$ 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 2: 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 $\mu A$ | 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 $^7Li$ 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

- The latest TPC hardware have been integrated into the system at the 90L flight path.
- LANSCE beams were stable and high quality data from U-235/U-238 mixed targets were collected using a full sextant of the TPC.
- Significant progress was made this quarter towards loading thin radioactive samples, including Pu-239, into the TPC.

## 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.

## 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.

### *New hardware integration at WNR*

This quarter, several new hardware and software components were integrated into the experimental setup at WNR. A new module was added to the Keithley 2701 multimeter: module 7706, which handles larger voltages and will complement the 7710 module already in place. In December, a filter circuit was shipped from LLNL to LANL to allow remote control of all high voltage power supplies. A power distribution unit was also shipped that can shut down all low voltage power supplies remotely, placing the TPC into a safe idle state that can be maintained indefinitely. Software components added to the system included slow control monitoring of beam current (Figure 33 and Figure 34); gas pressure and flow rates (Figure 35 and Figure 36); high voltage off and on controls; and low voltage off controls.

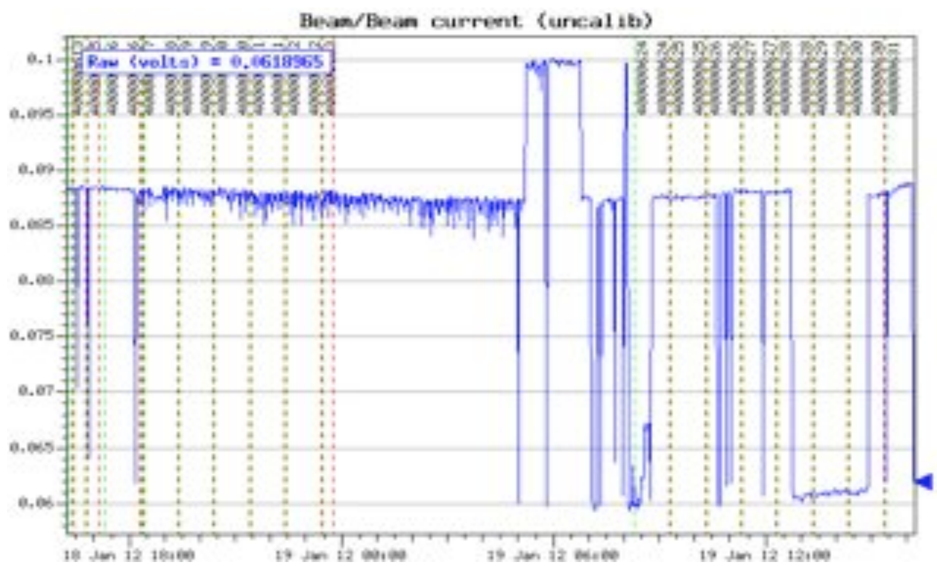


**Figure 33: Beam current as monitored by TPC slow controls system.**

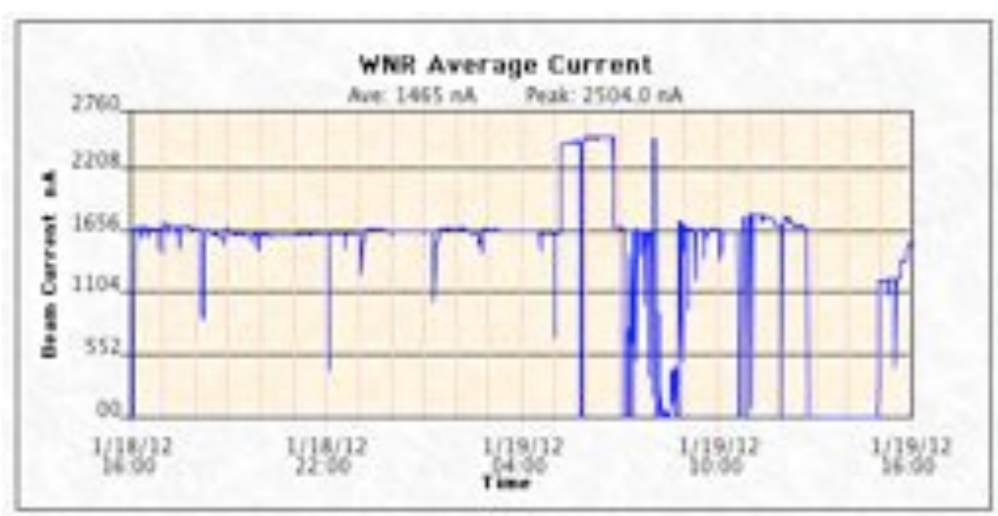


**Figure 34: Beam current as reported by LANSCE Operations.Radioactive sample loading.**

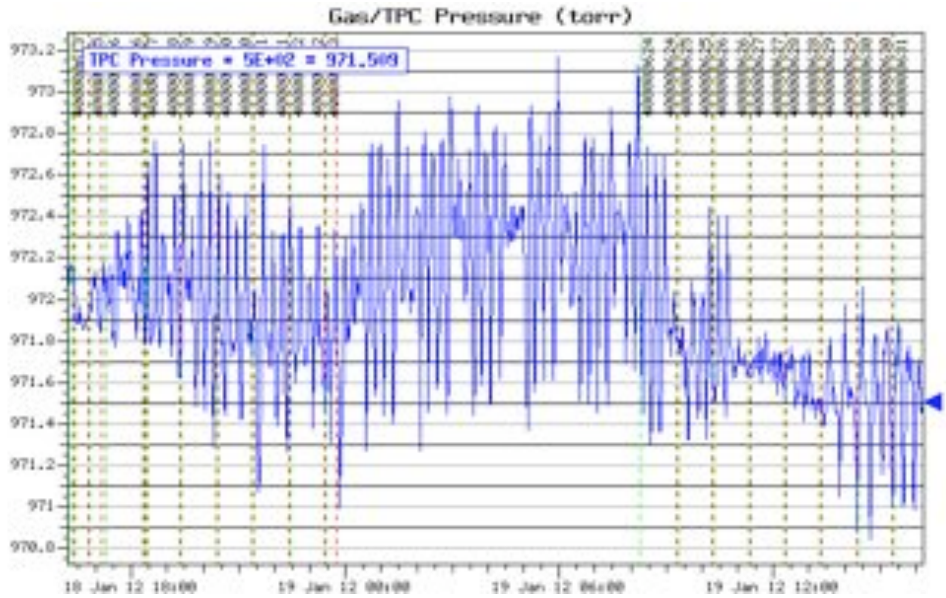


**Figure 35:TPC pressure as measured with high-accuracy pressure gauge and read out through slow controls.**

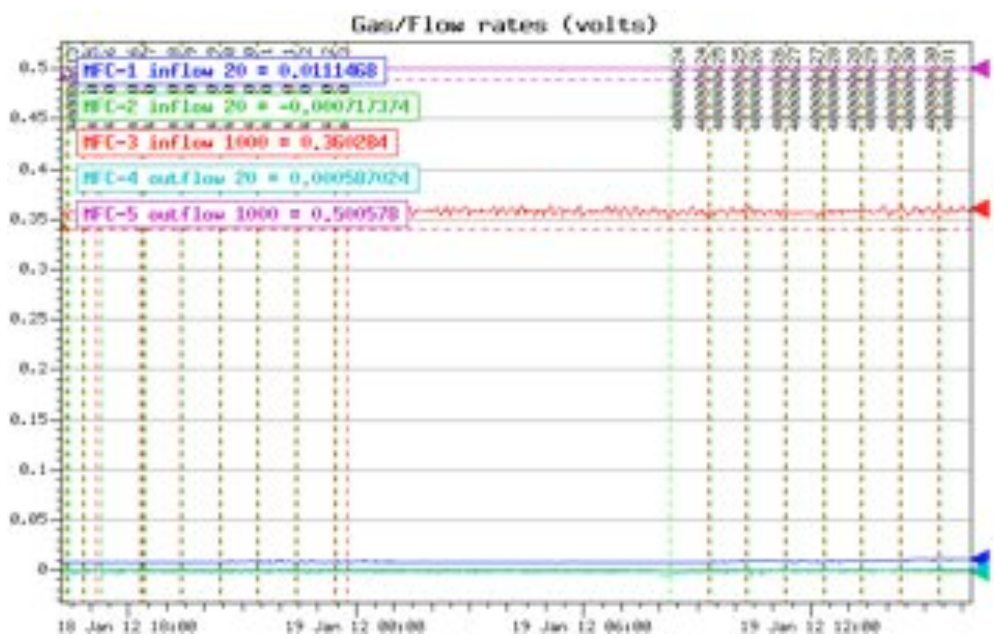


**Figure 36: TPC flow rates readout through slow controls.**

Significant progress was made this quarter towards loading thin radioactive samples (e.g. Pu-239) into the TPC. Two possible procedures were identified: (1) loading radioactive samples into field cages inside a glove box, sealing samples inside of field cages and transporting to a clean bench, unsealing and inserting samples into TPC on clean bench; and (2) inserting TPC into glovebox and opening, changing sample, and closing TPC entirely inside of the box. Infrastructure was developed for both procedures – sealing caps for the field cage for procedure (1) (Figure 37) and a TPC stand for the glove box for procedure (2) (**Figure 38**). Both procedures have been documented and practiced, and a decision is being made on which to pursue for the first Pu-239 run in FY2012. Safety documentation has been generated for each procedure, and for operation of TPC with radioactive samples on the 90L flight path.

**Figure 37: Top cap to seal radioactive samples into field cage.**

**Figure 38: Stand to securely hold TPC in glove box.**

### *Visitors and Documentation*

12 collaborators from 2 national laboratories (LLNL, INL) and 3 universities (ISU, ACU, CSM) came to WNR to help with setup and target changes during the first quarter of FY2012. This included three postdocs and three graduate students, U.S. citizens, and foreign nationals. With new visitor procedures in place, all collaborators were able to gain access to LANL and receive the required training in a prompt manner.

Several pieces of documentation were generated this quarter to record current running conditions and to facilitate information transfer amongst members of the collaboration (especially from old to new members). This included: TPC assembly manuals which take LANL infrastructure into consideration (all previous manuals had been written for LLNL); shift manuals for online and on-site shifters; and records of current experimental setup that can be used to help duplicate running conditions next year.

### *Data Runs*

The 2011 LANSCE run cycle began in October, with beam being delivered to the TPC flight path (90L) in November. As has been reported previously, 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 in the hundreds of MeV range is lower compared to the more forward flight paths. This is a relatively short flight path, with a nominal detector location of 10 meters from the neutron production target.

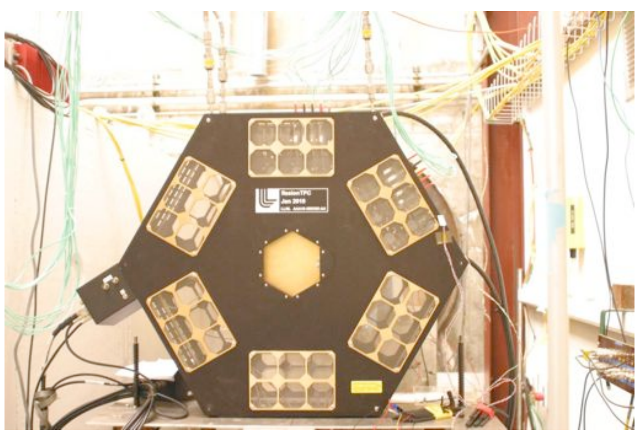

**Figure 39: TPC installed on the 90L flight path.**

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 40.

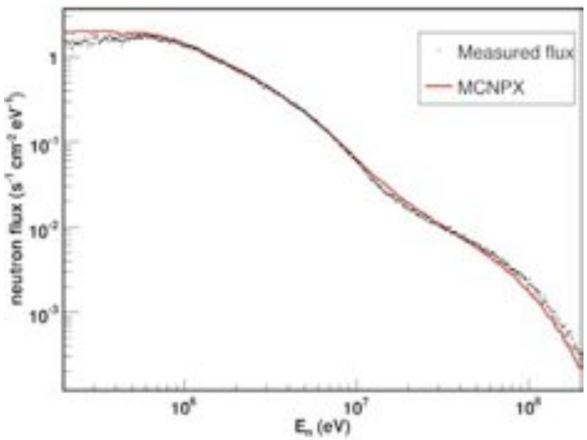


**Figure 40: Measured (black) and calculated (red) neutron flux on 90L.**

A new pad plane with one full sextant active area, pressure vessel, and set of 16 EtherDAQ cards were delivered to LANL in October. The prototype pad plane and pressure vessel from the 2010 run cycle were replaced with the new versions. The U-238 sample (areal density 229.2 μg/cm$^2$, evaporated onto a 111 μg/cm$^2$ thick carbon foil) used during the 2010 run cycle was kept in the field cage and inserted into the TPC. The gas handling system and all electronics were brought to 90L, inspected and connected to power. The TPC was brought to 90L and the EtherDAQ cards were installed. Data taking with the U-238 target commenced November 4, and continued until November 17. According to LANSCE operations, beam availability during this time was 95% (of scheduled time, which was limited to 12 hours/day because of construction activities outside of the flight path). A preliminary plot of track length vs. ADC taken during this period shows a clear separation between fission fragments and lighter particles (Figure 41).

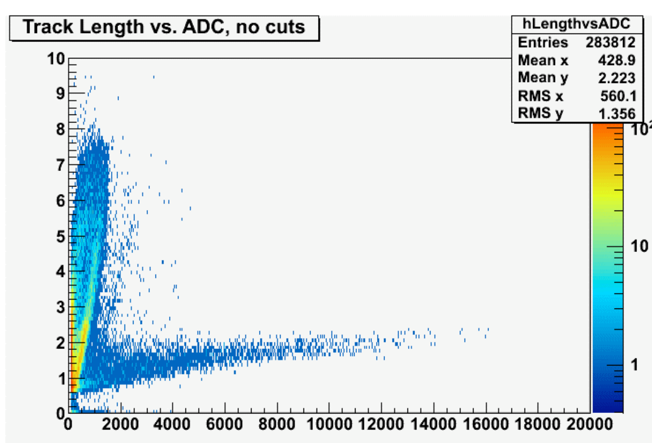


**Figure 41: Preliminary data taken during the first run of the 2011 LANSCE run cycle, with a U-238 target. Fission fragments can be seen (ADC > 2000) and clearly distinguished from lighter particles (such as alphas, ADC < 2000).**

During the November maintenance period, the U-238 target used in the first run of the 2011 run cycle was exchanged for a mixed isotope target: a ~200 µg/cm2 half-circle deposit of U-238 with a pie shaped wedge of U-235 (~100 µg/cm$^2$ thick) opposite it (Figure 42). Initially, this sample was placed into the TPC facing the inactive pad plane, and background data on the Al backing was taken for approximately 7 days (November 29 – December 8). The sample was then flipped so that the actinide deposits faced the active pad plane and data was taken for another week (December 8 – 17). A preliminary plot from this run period is shown in Figure 43. According to LANSCE operations, beam availability during this run was 90% (of scheduled time, still 12 hrs/day due to construction).

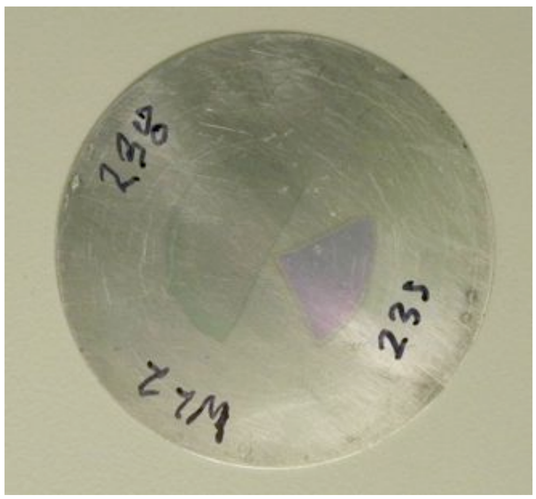


**Figure 42: Mixed isotope target used in December run.**

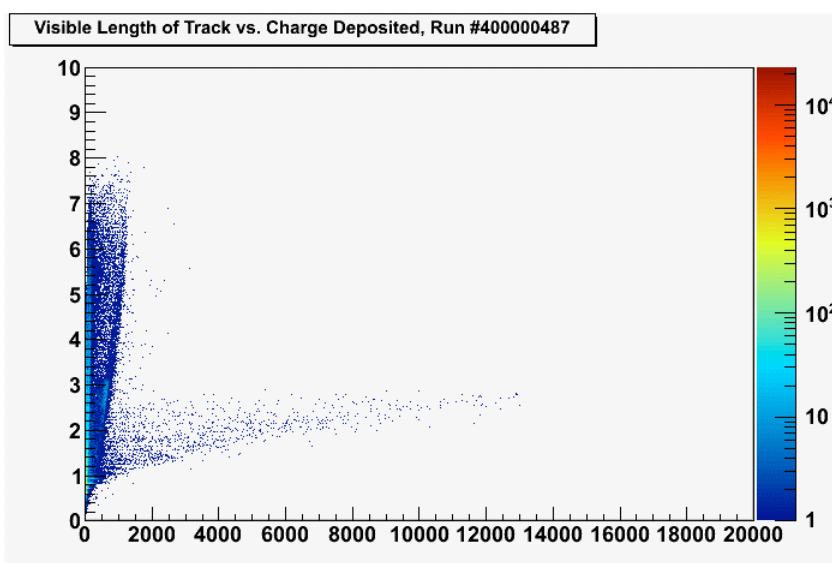


**Figure 43: Preliminary plot from December run.**

Following the December run all EtherDAQ cards were removed from the TPC and safely stored. The TPC was disconnected from all equipment, and was secured for long time storage over the holiday break.

### *WNR construction*

Construction of a new building that will cover a large part of the WNR south yard continues. The building will be adjacent to the 90L flight path, and the entrance to 90L will be located inside the new building. New work space will be available for the TPC project which will likely lead to a reconfiguration of the currently used space.

The construction project has run into a number of delays, with the most significant one being caused by issues related to compaction of the soil in preparation for the slab that makes up the foundation for the building. Progress was made in October with the concrete pit for the Chi-Nu project being completed. Finally, on December 29, concrete was poured outside of the 90L flight path completing the slab.

A break in the construction project will be in effect for January and February 2012, which means that beam operations can return to 24 hours/day for the remainder of the LANSCE-WNR run cycle.

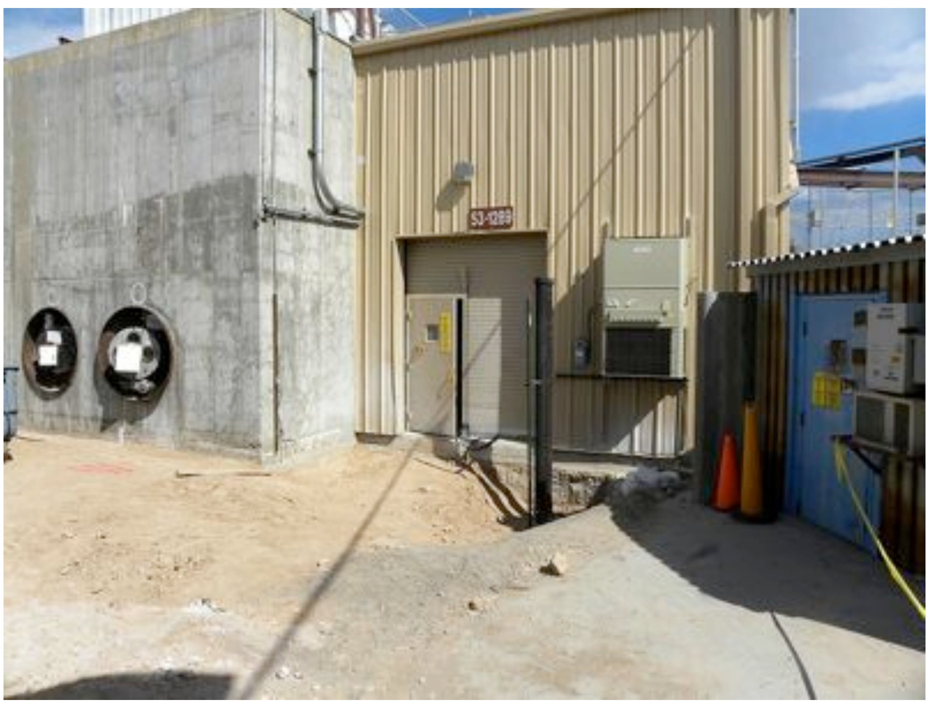


**Figure 44: The 90L flight path in early October 2011.**

**Figure 45: The WNR south yard after the concrete slab was poured on December 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.

# 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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