National Superconducting Cyclotron Laboratory
Proposal Data Form—PAC 31

TITLE: Re-Commissioning and Calibration of the Large Area Neutron Array

By submitting this proposal, the spokesperson certifies that all collaborators listed have read the proposal and have agreed to participate in the experiment.

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BACKUP SPOKESPERSON: ______________________

Institution: ______________________

Phone: ____________ Fax: ____________ E-Mail : ____________

OTHER EXPERIMENTERS: (Please spell out first name and indicate Graduate Students (GS), Undergraduate students (UG) and Postdoctoral Associates (PD))

Last name, First name	**Organization**	**Last name, First name**	**Organization**
Ravin Kodikara (GS)	WMU		
Subramanian Vilayaganapathy (GS)	WMU		
Brenna Giacherio (GS)	WMU		

REQUEST FOR PRIMARY BEAM SEQUENCE INCLUDING TUNING, TEST RUNS, AND IN-BEAM CALIBRATIONS: (Summary of information provided on Beam Request Worksheet(s). Make separate entries for repeat occurrences of the same primary beam arising from user-requested interruptions to the experiment.)

	Isotope	Energy (MeV/nucl.)	Minimum Intensity (particle-nanoampere)	Sum of Beam Preparation Times (Hours)	Sum of Beam-On-Target Times (Hours)
Beam 1	^{18}O	125	120	32	96
Beam 2					
Beam 3					
Beam 4					

ADDITIONAL TIME REQUIREMENTS THAT REQUIRE USE OF THE CCF (e.g. modification of the A1900 standard configuration, development of optics, … Obtain estimates from the A1900 Device Contact.)

Additional CCF use time: 0

Total Hours: 32 | 96

TOTAL TIME REQUEST (HOURS): 128
(Calculated as per item 4. of the Notes for PAC 31 in the Call for Proposals)

HOURS APPROVED: ____________ HOURS RESERVED: ____________

Access to:		SET UP TIME (before start of beam)	TAKE DOWN TIME
	Experimental Vault	10 days	4 days
	Electronics Set-up Area	4 days	2 days

NSCL PAC 31 – 3. Proposal Data Form

Data Acquisition Computer _4_ days _2_ days

WHEN WILL YOUR EXPERIMENT BE READY TO RUN? 11 / 20 / 2007

DATES EXCLUDED: ____

EXPERIMENTAL LOCATION:

___	Transfer Hall (in the A1900)	___	Transfer Hall (downstream of the A1900)
___	N2 vault (with 92" chamber)	___	N2 vault (92" chamber removed)
___	N2 vault (with Sweeper line)	___	N4 vault (Gas stopping line)
___	S1 vault (Irradiation line)	_X_	S2 vault
___	S3 Vault		

EXPERIMENTAL EQUIPMENT:

___	A1900	___	Beta Counting System	___	Beta-NMR Apparatus
___	92" Chamber	___	Sweeper Magnet	_X_	Neutron Walls
___	Modular Neutron Array	___	Neutron Emission Ratio Observer		
___	High Resolution Array	___	APEX NaI Array		

___ Segmented Ge Array [ ] classic [ ] mini [ ] beta [ ] delta [ ] plunger [ ] barrel [ ] other

___ S800 Spectrograph [ ] with [ ] without scattering chamber

___ Other (give details)

DETAIL ANY MODIFICATION TO THE STANDARD CONFIGURATION OF THE DEVICE USED, OR CHECK NONE: [ ] NONE

DETAIL ANY REQUIREMENTS THAT ARE OUTSIDE THE CURRENT NSCL OPERATING ENVELOPE, OR CHECK NONE (Examples: vault reconfiguration, new primary beam, primary beam intensities above what is presently offered, special optics, operation at unusually high or low rigidities): [ ] NONE

TARGETS:

Plastic (CH_2)

LIST ALL RESOURCES THAT YOU REQUEST THE NSCL TO PROVIDE FOR YOUR EXPERIMENT BEYOND THE STANDARD RESOURCES OUTLINED IN ITEM 11. OF THE NOTES FOR PAC 30 IN THE CALL FOR PROPOSALS.

LIST ANY INTERRUPTIONS REQUIRED IN RUNNING YOUR EXPERIMENT: (Examples of why an experiment might need an interruption: to change the experimental configuration; to complete the design of an experimental component based on an initial measurement.)

OTHER SPECIAL REQUIREMENTS: (Safety related items are listed separately on following pages.)

SUMMARY (no more than 200 words):

Description of Experiment

(no more than 4 pages of text for items 1through 3 - 1 1/2 spaced, 12pt; no limit on figures or tables)

Please organize material under the following headings or their equivalent:

1. Physics justification, including background and references.
2. Goals of proposed experiment
3. Experimental details—apparatus (enclose sketch); what is to be measured; feasibility of measurement; count rate estimate (including assumptions); basis of time request (include time for calibration beams, test runs, and beam particle or energy changes); technical assistance or apparatus construction requested from the NSCL.

Note: Graphics should be such that black-and-white copies will convey the intended information correctly; references to color should be avoided.

Physics Justification

Neutron detection remains a powerful tool in studies of nuclear structure,[i] astrophysics,[ii] and the equation-of-state. In particular, isotopic observables of the asymmetry term of the nuclear EOS have concentrated on flow observables,[iii] isoscaling,[iv] and – very recently – neutron/proton emission ratios.[v,vi] Future experimentation to study the asymmetry dependence of the nuclear EOS at the NSCL will concentrate on constraining the model dependence of results by measuring the isospin dependence of in-medium nucleon-nucleon (NN) cross-sections. Such experimentation requires a complex setup including a charged-particle array with good angular and energy resolution, a multiplicity detector to gauge collision centrality, a fast timing trigger detector, and a neutron array with a large angular coverage. For this reason, the NSCL has undertaken a project to reconfigure the S2 vault as a neutron TOF area. The resulting area will provide a versatile, permanent, yet easily configurable setup to mount and run neutron TOF experiments using the Large Area Neutron Array.[vii,viii] The first experiment to run in the S2 vault is the approved NSCL experiment #05049.

An ongoing difficulty with neutron detection is the accurate calibration of the detector. While neutron energy in the S2 vault can be measured via TOF to the array, the detection efficiency as a function of neutron energy and threshold is crucial to experiments such as cross-section experiments or spectral ratio experiments for which an accurate neutron count is necessary. Calibration techniques have included using monoenergetic neutron beams,[ix] source calibrations,[x] and the “associated particle” technique.[xi] The associated particle relies on constraining the kinematics of a neutron in a reaction by measuring the angle and/or energy of an associated charged particle. An example is the calibration of a neutron detector using the

^{7}Li(p,n)^{7}Be reaction by measuring the ^{7}Be angle and energy.[xii] This technique is quite convenient at facilities such as the NSCL, which can provide a high-intensity, high-purity beam with a small momentum spread.

Upcoming neutron experimentation in the S2 vault – in particular, the aforementioned experiment #05049, will require an accurate calibration of the efficiency of the neutron array located in the vault. An efficiency as a function of neutron energy at low threshold is sufficient to constrain the efficiency at higher thresholds, as the PMT charge signal in individual elements of the wall can be used to study the threshold by making artificial energy (charge, or QDC) cuts in the resulting data. Efficiency as a function of position is also necessary at lower energies, as the light collection may be reduced due to attenuation from one end of the tube to the other. Comparison to simulations should also be made.

<u>Goals of the Proposed Experiment</u>

The proposed experiment is to re-commission the Large Area Neutron Array as a part of the ongoing experimental program at the NSCL neutron TOF area. Using the p(t,^{3}He) reaction, the experimenters propose to measure the neutron detection efficiency as a function of neutron energy, electronic threshold, and hit position within the Large Area Neutron Array. Neutron energy can be determined redundantly using TOF and by constraining the reactions kinematics with the ^{3}He angle and energy in the HiRA detector. Efficiency as a function of electronic threshold can be determined in the resulting data analysis, and hit position in individual tubes in the neutron array can be determined using TOF difference between tubes on either side of the wall. Background and scattering effects will also be measured. The position dependence of efficiency can be determined by using two beam energies, thus allowing for a single neutron energy event at multiple locations on the wall.

<u>Experimental Details</u>

The experimental setup is shown in Figure 1. The proposed setup will be identical to that used for NSCL experiment #03045. Neutron walls will be placed as shown, with an angular coverage of roughly 10^{0} to 55^{0}. The HiRA array will be placed on the opposite side of the beam with an angular coverage of $10^{0} – 20^{0}$. ^{3}He particles from reactions in the target will be detected in the HiRA array with an angular resolution of 0.32^{0} and an energy resolution of about 60 keV. In this way, the energy and angle of the outgoing neutron will be constrained. The position of the neutron in individual wall tubes will not only provide efficiency information, but will also provide the precise position of every tube in the vault relative to the target. While not necessary, neutron TOF to the walls can be determined using an optional thin scintillator or diamond detector at the target position.

The kinematics of the p(t,^{3}He)n reaction is shown in Figure 2 – 5 for triton beams of 50 MeV/A and 21 MeV/A. Two beam energies allows for a wide energy coverage of the neutron walls while maintaining the vault configuration without moving the walls. The beam energies listed are complementary in that each provides a different energy range for incident neutrons. A small overlap in neutron energy will also allow for a measurement of the dependence of efficiency across an individual tube of the array by providing for multiple measurement locations for a neutron of the same energy.

The tritium beams can be produced using a ^{18}O primary beam at 120 MeV/A on a thick (3200 mg/cm^2) Be target. Beam purity can be improved to nearly 100% using a wedge at the F2 focal point of the A1900. Previous measurements of the triton production from a ^{18}O beam have produced yields about a factor of 6 higher than those produced in LISE calculations.[xiii] For a momentum acceptance $\Delta p/p$=0.5%, a calculated yield (using LISE) of 30000 s^{-1}pnA^{-1} of ^{3}H at 50 MeV/A is calculated. Given the calculated yields and the results from reference xiii, a triton production of 3.6×10^{6} s^{-1} can be expected with a tight momentum acceptance. For a ^{3}H energy of 21 MeV/A, a rate of 9.84×10^{5} s^{-1} is predicted with a 1% momentum acceptance at the A1900 intermediate image. Tritium production rates are shown in Table 1.

The predicted neutron detection efficiency has been simulated using the detector GEANT.[xiv] Neutron detection efficiency as a function of neutron energy, detection threshold, and incident position in the wall has been estimated using a simulation of individual tubes in the Large Area Neutron Array. Detection efficiencies as a function of neutron energy for various thresholds are shown in

Figure 6. Estimated event rates in the array have been calculated using the results of this simulation. The proposed experiment will utilize a low threshold. For this reason, calculated efficiencies which assume a threshold of 1MeV are used for rate estimates.

The cross section for the p(t,^{3}He)n reaction has been measured at 21 MeV/A,[xv] and the differential cross section for neutron detection is shown in Figure 7 for laboratory angles occupied by neutron wall B, as shown in Figure 1. From this figure total detection rates can be estimated in various sections of the neutron array. Rates of neutrons incident on the wall are listed in Table 2. In this table, the wall is subdivided into 4^0 segments, and the estimated number of detected neutrons in each segment are listed. The number of detected neutrons is based on a simulated minimum detection efficiency of 10%; the actual value could vary by a few percent.

The angular uncertainty for ^{3}He detection in the HiRA array is constrained by the pixel size of 2mm. At a design distance of 35 cm, each pixel occupies an angular region of 5.7 mrad (0.33^0). An additional angular uncertainty due to the uncertainty of the beam emittance is induced. Using the LISE transport code, an uncertainty in the angular distribution of 1^0 at the focal plane of the A1900 is assumed. The total angular uncertainty for charged-particle detection is thus estimated at 1.05^0. (Emittance at the target may be improved using beam cutting optics in the S2 vault at the expense of beam rate.) This corresponds to a comparable angular uncertainty in the neutron array in this geometry, and the resulting uncertainty in the neutron energy is about 1 MeV for most of the detected particles. The uncertainty in the neutron energy and angle is also constrained with a measurement of the ^{3}He energy in the HiRA array. For events with an energy less than 45 MeV (15 MeV/A – nearly all charged particles emitted if the beam energy is 21 MeV/A), particles will stop in the 1mm silicon detector of the HiRA array, with an energy resolution of about 60 keV, corresponding to an uncertainty in the neutron energy of 180 keV – sufficient for this sort of efficiency calibration. Further, an optional thin scintillator or diamond detector is proposed near the target position to measure the neutron TOF using the target detector as the trigger for the start time, and the neutron array as the stop detector.

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[i] Review article on neutron detection, s.p. states.
[ii] R-process reference (n s.p. states) (Wallerstein?)
[iii] Li paper on transverse flow.
[iv] Liu, tsang, etc.
[v] Li paper
[vi] Famiano n/p paper
[vii] Galonsky paper.
[viii] Galonsky paper LANA
[ix] Monoenergetic beam technique (OU)?
[x] Source calibration technique
[xi] Associated particle calibration.
[xii] Be-7 measurement
[xiii] Hitt, W.G., et al., NIMA, submitted (2006).
[xiv] GEANT reference
[xv] Allas, R.G., et al., Phys. Rev. C 9, 787 (1974).

Table 1 - Beam energy, neutron rates, and estimated detection rates of neutrons for each beam.

^{3}H Energy (MeV/A)	Predicted Rate ($s^{-1}pnA^{-1}$)	Energy Range of Incident Neutrons (MeV)	Total Neutron Rate on Walls ($10^{-3}s^{-1}pnA^{-1}$)	Estimated Total Detected Neutrons (48hrs)
50	30000	45 - 108	33.5	69464
21	8200	14 - 45[f1]		4500

Table 2 - Neutron detection rates using estimated cross sections.

^{3}H Energy (MeV/A)	Neutron Array Angular Range (degrees)	Incident Neutron Energy (MeV)	Estimated Rate Incident on Wall ($10^{-3}s^{-1}pnA^{-1}$)	Estimated Total Detected Neutrons (48hrs)
21	10 – 14	43 – 45		
	14 – 18	42 – 43		
	18 – 22	39 – 42		
	22 – 26	37 – 39		
	30 - 34	31 – 35		
	34 - 38	28 - 31	[f2]	
	38 – 42	25 - 28	1.2	2380
	42 – 46	21 - 25	1.7	3570
	46 - 50	18 - 21		
		Total	**0.26**	**4500**
50	10 – 14	105 – 108	5.1	10575
	14 – 18	100 – 105	4.7	9746
	18 – 22	95 – 100	4.3	8916
	22 – 26	89 – 95	3.7	7672
	30 - 34	76 – 83	4.4	9124
	34 - 38	68 – 76	3.7	7672
	38 – 42	61 – 68	3.1	6428
	42 – 46	53 – 61	2.5	5184
	46 - 50	45 - 53	2.0	4147
		Total	**33.5**	**69465**

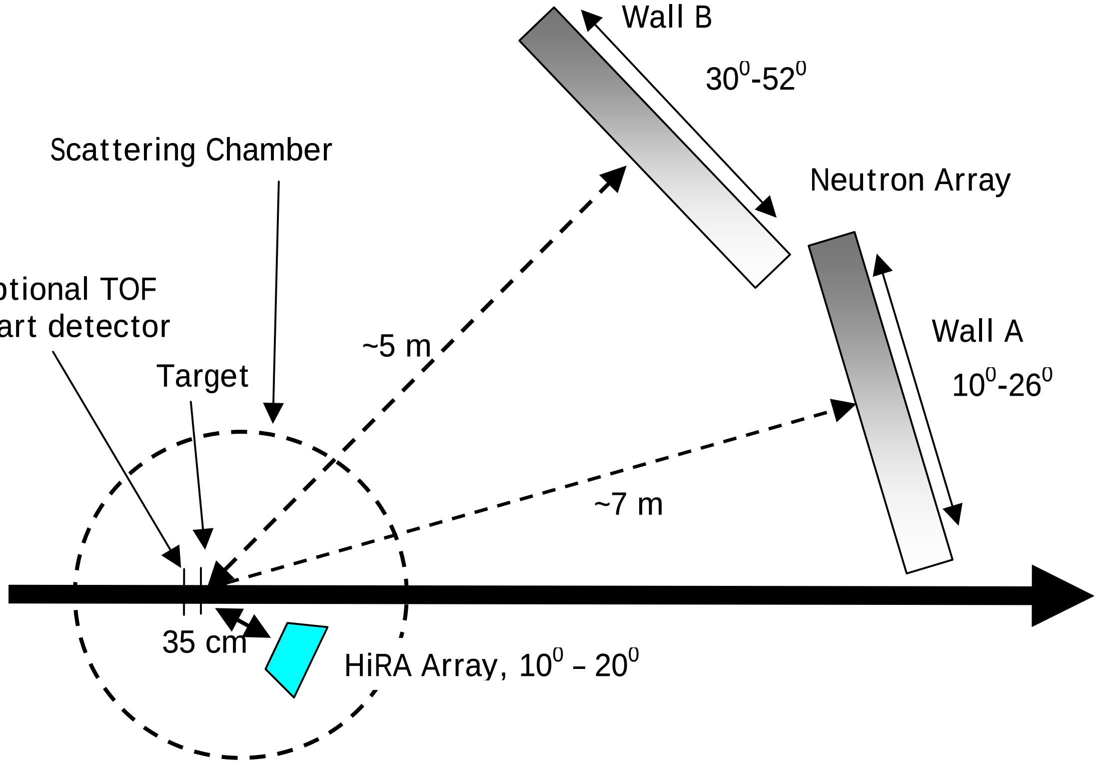

Figure 1 - Experimental setup schematic showing the neutron wall array and HiRA array with respect to the target. The HiRA array is contained with the target within a thin-walled scattering chamber.

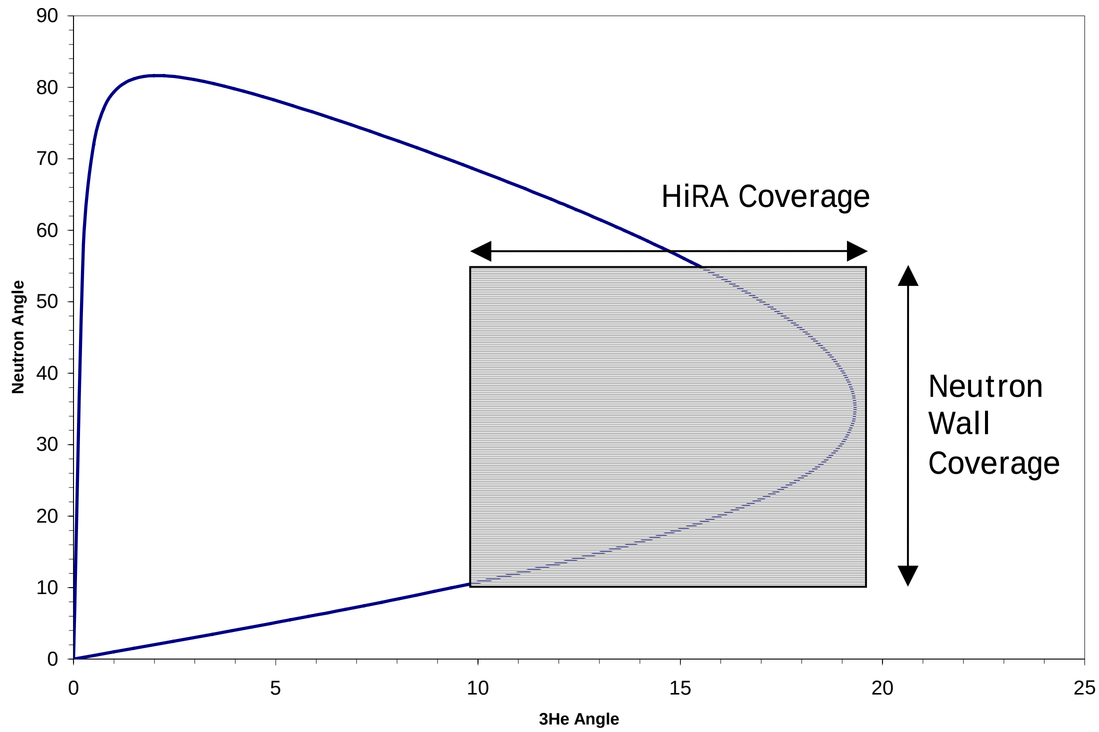

Figure 2 – Angular relationship p(t,3He)n reaction at a beam energy of 50 MeV/A in the laboratory frame for the outgoing neutron and 3He particle. The angular coverage of the neutron wall and HiRA array is also indicated by the shaded region.

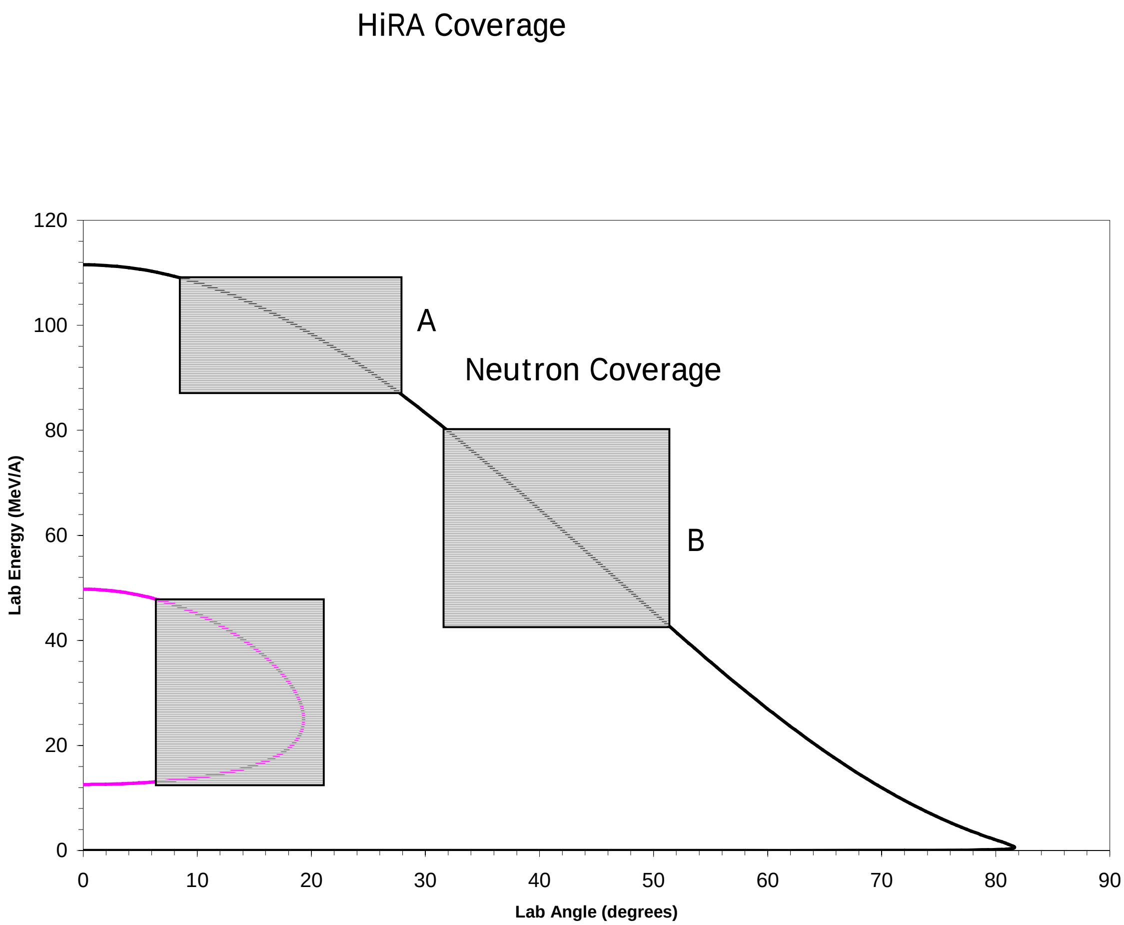

Figure 3 - Lab energy and angle of the neutron and 3He in the p(t,3He)n reaction at a beam energy of 50 MeV/A. The coverage by the neutron walls – labeled as indicated in Figure 1 - and the HiRA array is indicated by the shaded region.

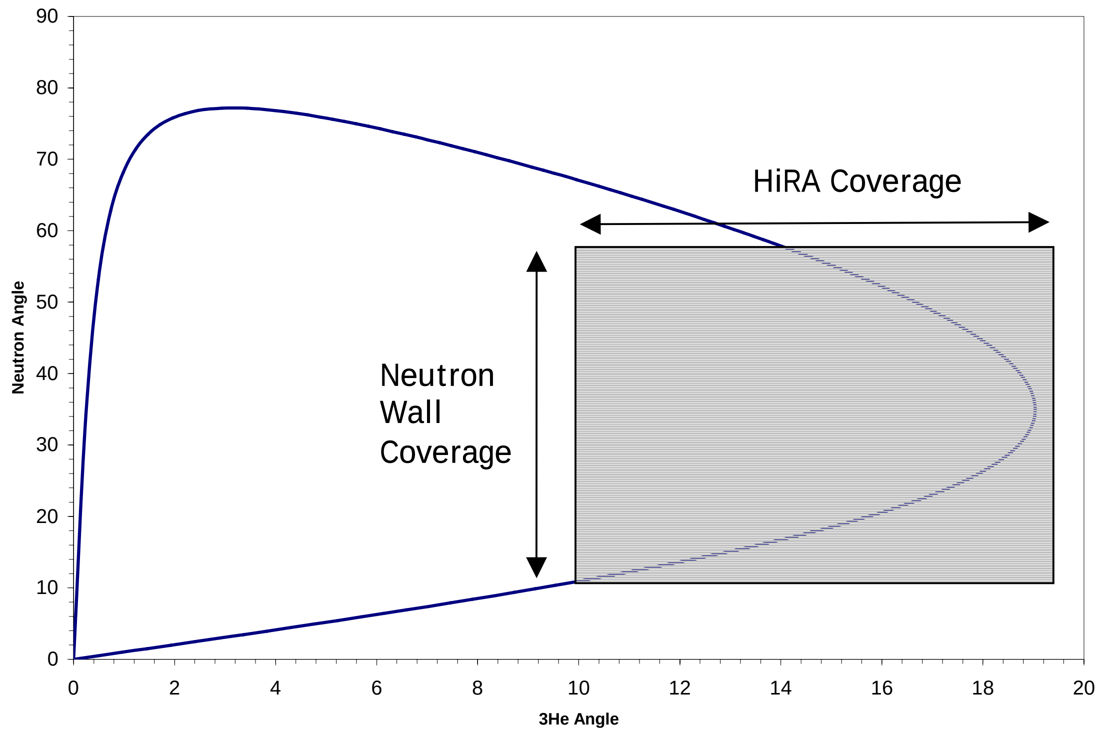

Figure 4 - Same as for Figure 2, but for a beam energy of 21 MeV/A.

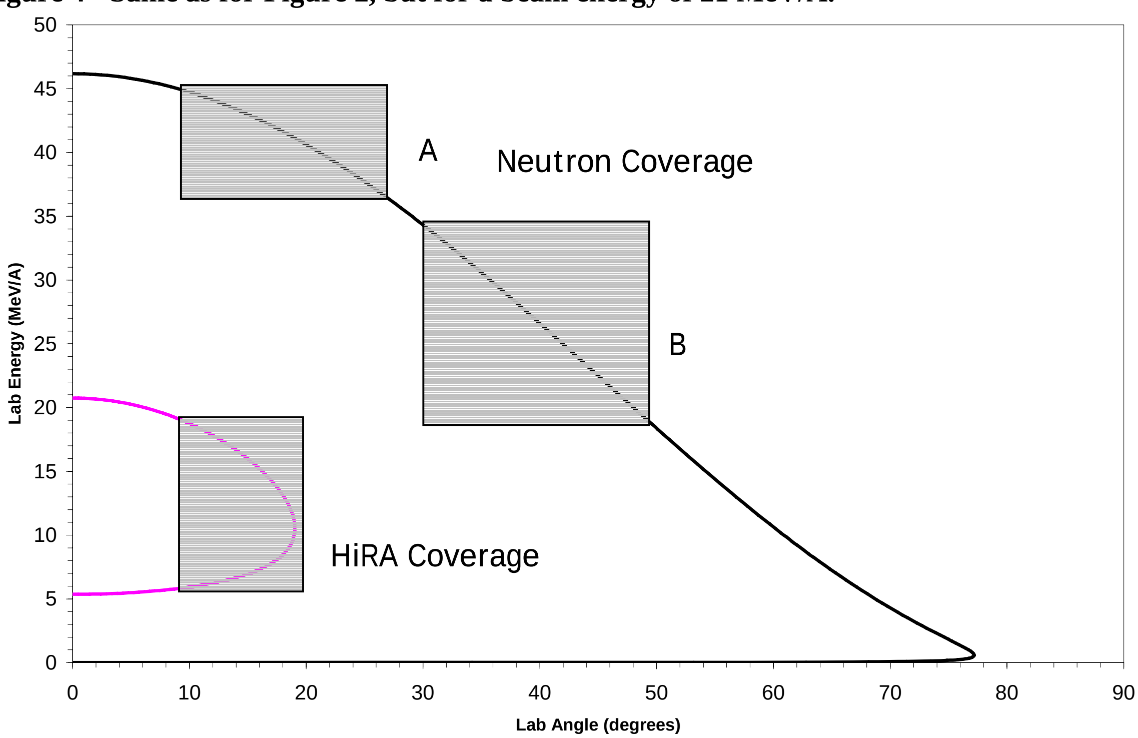

Figure 5 - Same as Figure 3, but for a beam energy of 21 MeV/A.

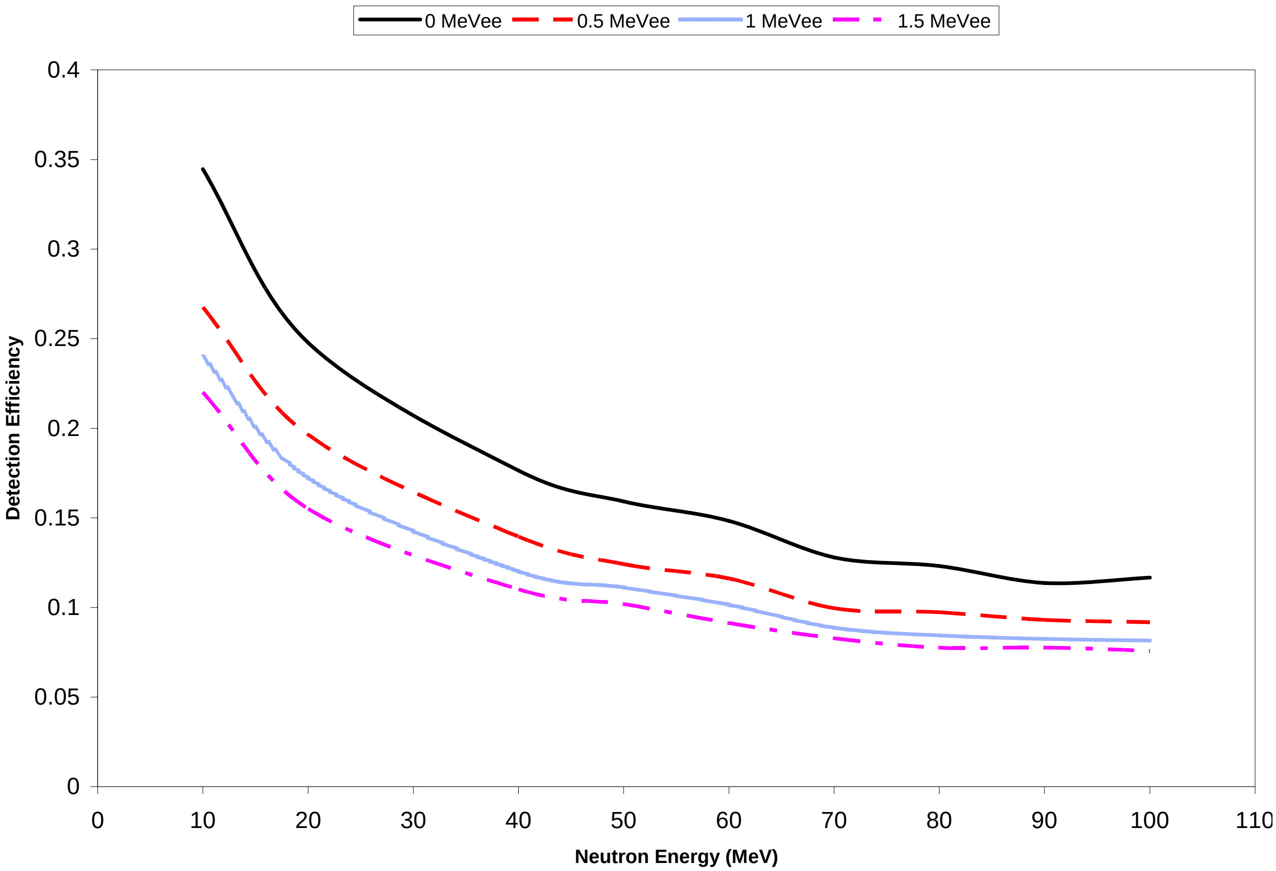

Figure 6 - Simulated neutron detection efficiency as a function of neutron energy for various detection thresholds.

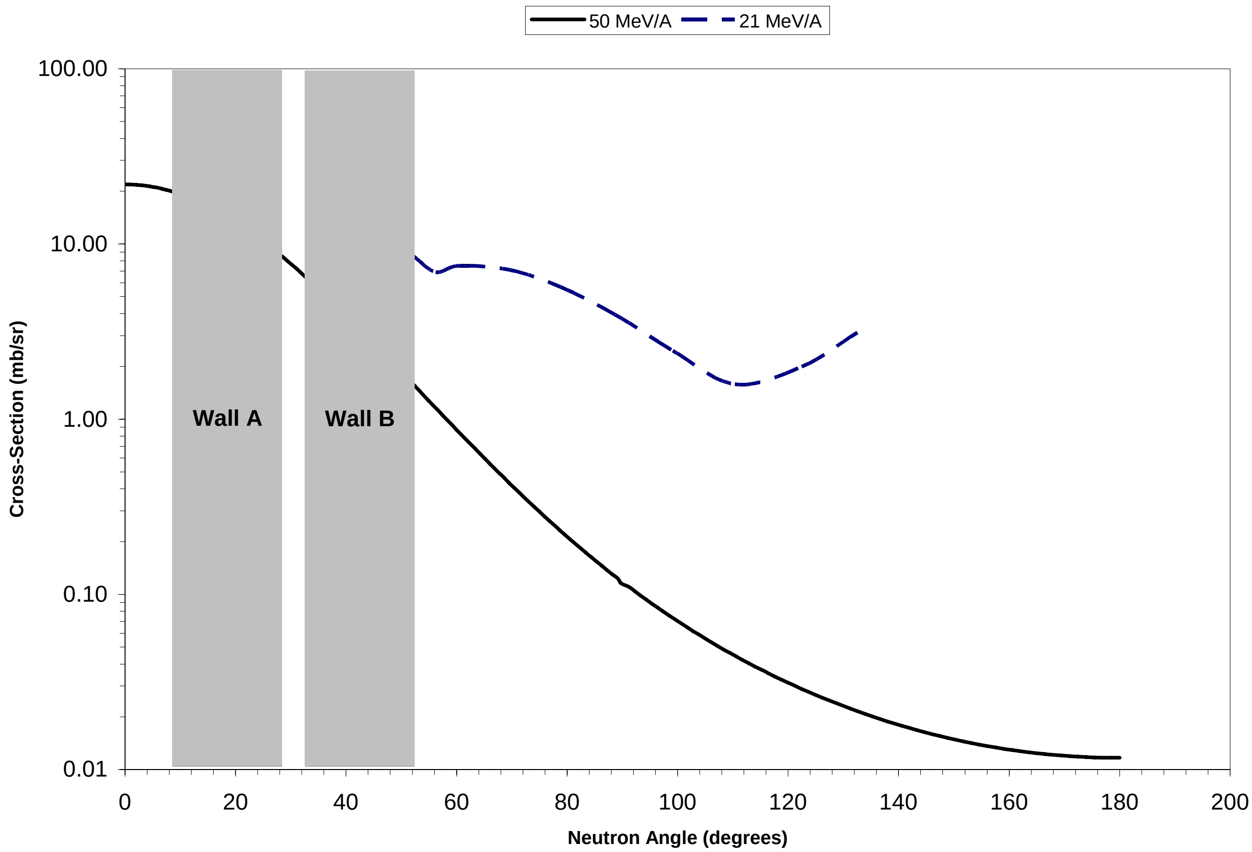

Figure 7 - Differential cross section for the reaction p(t,3He)n at 21 MeV/A and 50 MeV/A. The coverage of the neutron array is indicated.

Status of Previous Experiments

Results from, or status of analysis of, previous experiments at the CCF listed by experiment number. Please indicate publications, presentations, Ph.D.s awarded, Master's degrees awarded, undergraduate theses completed.

The following description corresponds to recent experiments in which the spokesperson held a leading or important role. While the spokesperson was involved in at least six approved NSCL experiments in the past year, only a few recent representative experiments are given here.

Recent experimental efforts have explored the isospin dependence of the asymmetry term at sub-saturation densities. Most recently, NSCL experiment #03045 has been successfully completed to study proton-proton correlations as a sensitive observable of the asymmetry term of the nuclear EOS, and analysis is underway as a thesis experiment for NSCL graduate student Micah Kilburn.

Experiment #01032, which is very similar to the proposed experiment in scope and setup, was completed with the successful publication of results by the primary spokesperson.[1] Results from this experiment have been presented at the Seaborg Award Symposium of the 2005 Meeting of the American Chemical Society, the 2006 Gordon Research Conference on Nuclear Chemistry, and numerous other meetings.

The proposed experiment will be part of the program initiated by the approved NSCL experiment #05049. The experimental configuration for the proposed experiment will be nearly identical to that used for #05049. Setup for the proposed experiment should be minimal.

The spokesperson recently completed NSCL experiment #02023 to measure the proton breakup energy of the rp-process nucleus ^{69}Br. This experiment will be the primary thesis experiment of NSCL graduate student Andrew Rogers, who is currently proceeding through the analysis. Currently, device calibration is nearly complete for this experiment, including complete calibration of the S800 device and the HiRA device. Preliminary results are now being extracted.

The development of the High Resolution Array, was necessary for the successful completion of all of the above experiments. A description of this device has been submitted for publication.[2] Development of this device, which was commissioned in NSCL experiment #03014, has been a considerable portion of the thesis work of NSCL graduate Mark Wallace.

[1] Famiano, M.A. et al. Phys. Rev. Lett. 97, 052701 (2006).
[2] Wallace, M.S., Famiano, M.A., et al. NIMA, submitted (2006).

Educational Impact of Proposed Experiment

If the experiment will be part of a thesis project, please include how many years the student has been in school, what other experiments the student has participated in at the NSCL and elsewhere (explicitly identify the experiments done as part of thesis work), and whether the proposed measurement will complete the thesis work.

This experiment will be part of the thesis experiments of Subramanian (Subba) Vilayaganapathy, a graduate students of the primary spokesperson at Western Michigan University (WMU), and will be necessary to the successful completion of their thesis work. Both students are entering their third year of graduate school.

In addition to thesis work, the proposed experiment provides an excellent opportunity for graduate and undergraduate education. Three WMU graduate students will participate in the setup and running of the experiment, and three undergraduate students will participate, including a computer science student who will be primarily responsible for data acquisition and online analysis routines.

Safety Information

It is an important goal of the NSCL that users perform their experiments safely, as emphasized in the Director's Safety Statement. Your proposal will be reviewed for safety issues by committees at the NSCL and MSU who will provide reviews to the PAC and to you. If your experiment is approved, a more detailed review will be required prior to scheduling and you will need to designate a Safety Representative for your experiment.

SAFETY CONTACT FOR THIS PROPOSAL:

____

HAZARD ASSESSMENTS (CHECK ALL ITEMS THAT MAY APPLY TO YOUR EXPERIMENT):

____X____ Radioactive sources required for checks or calibrations.
__________ Transport or send radioactive materials to or from the NSCL.
__________ Transport or send— to or from the NSCL—chemicals or materials that may be considered hazardous or toxic.
__________ Generate or dispose of chemicals or materials that may be considered hazardous or toxic.
__________ Mixed Waste (RCRA) will be generated and/or will need disposal.
__________ Flammable compressed gases needed.
__________ High-Voltage equipment (Non-standard equipment with > 30 Volts).
__________ User-supplied pressure or vacuum vessels, gas detectors.
__________ Non-ionizing radiation sources (microwave, class III or IV lasers, etc.).
__________ Biohazardous materials.

PLEASE PROVIDE BRIEF DETAIL ABOUT EACH CHECKED ITEM.

Alpha test sources for testing charged-particle array (e.g., ^{228}Th).
Neutron test sources for wall testing (e.g., ^{252}Cf, PuBe, AmBe)
Various gamma test sources for rough wall gain matching (e.g., ^{60}Co, ^{228}Th, PuBe)

Beam Request Worksheet Instructions

Please use a separate worksheet for each distinct beam-on-target requested for the experiment. Do not forget to include any beams needed for calibration or testing. This form does not apply for experiments based in the A1900. Note the following:

(a) **Beam Preparation Time** is the time required by the NSCL for beam development and beam delivery. This time is calculated as per item 4. of the Notes for PAC 30 in the Call for Proposals. This time is not part of the time available for performing the experiment.

(b) **Beam-On-Target Time** is the time that the beam is needed by experimenters for the purpose of performing the experiment, including such activities as experimental device tuning (for both supported and non-supported devices), debugging the experimental setup, calibrations, and test runs.

(c) The experimental device tuning time (XDT) for a supported device is calculated as per item 5. of the Notes for PAC 30 in the Call for Proposals. For a non-supported device, the contact person for the device can help in making the estimate. In general, XDT is needed only once per experiment but there are exceptions, e.g. a change of optics for the S800 will require a new XDT. When in doubt, please consult the appropriate contact person.

(d) A **primary beam** can be delivered as an on-target beam for the experiment either at the full beam energy or at a reduced energy by passing it through a degrader of appropriate thickness. The process of reducing the beam energy using a degrader necessarily reduces the quality of the beam. Please use a separate worksheet for each energy request from a single primary beam.

(e) Report the Beam-On-Target **rate** in units of particles per second per particle-nanoampere (pps/pnA) for secondary beams or in units of particle-nanoampere (pnA) for primary or degraded primary beams.

(f) More information about **momentum correction** and **timing start signal** rate limits are given in the A1900 service level description.

(g) For rare-isotope beam experiments, please remember to send an electronic copy of the LISE++ files used to obtain intensity estimates.

Beam Request Worksheet

Please use a separate sheet for each distinct beam-on-target requested

			Beam Preparation Time	Beam-On-Target Time
Primary Beam (from beam list)				
Isotope	^{18}O			
Energy	125	MeV/nucleon		
Minimum intensity	120	particle-nanoampere		
Tuning time (16 hrs; 0 hrs if the beam is already listed in an earlier worksheet):			16 hrs	
Beam-On-Target				
Isotope	^{3}H			
Energy	50	MeV/nucleon		
Rate at A1900 focal plane	30000	pps/pnA (secondary beam) or pnA (primary beam)		
Total A1900 momentum acceptance	1	% (e.g. 1%, not ±0.5%)		
Minimum Acceptable purity	99.9	%		
Additional requirements	[ ]	Event-by-event momentum correction from position in A1900 Image 2 measured with [ ] PPAC [ ] Scintillator		
	[ ]	Timing start signal from A1900 extended focal plane		
Delivery time per table (or 0 hrs for primary/degraded primary beam):			4 hrs	
Tuning time to vault:			4 hrs	
Total beam preparation time for this beam:			**24 hrs**	
Experimental device tuning time [see note (c) above]: S800 [ ] SeGA [ ] Sweeper [ ] Other [ ]				0 hrs
On-target time excluding device tuning:				48 hrs
Total on-target time for this beam:				**48 hrs**

Beam Request Worksheet

Please use a separate sheet for each distinct beam-on-target requested

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope	^{18}O	
Energy	125	MeV/nucleon
Minimum intensity	120	particle-nanoampere

Tuning time (16 hrs; 0 hrs if the beam is already listed in an earlier worksheet): 0 hrs

Beam-On-Target

Isotope	^{3}H	
Energy	21	MeV/nucleon
Rate at A1900 focal plane	8200	pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance	1	% (e.g. 1%, not ±0.5%)
Minimum Acceptable purity	99.9	%
Additional requirements	[ ]	Event-by-event momentum correction from position in A1900 Image 2 measured with [ ] PPAC [ ] Scintillator
	[ ]	Timing start signal from A1900 extended focal plane

Delivery time per table (or 0 hrs for primary/degraded primary beam): 4 hrs

Tuning time to vault: 4 hrs

Total beam preparation time for this beam: **8** **hrs**

Experimental device tuning time [see note (c) above]: 0 hrs
S800 [ ] SeGA [ ] Sweeper [ ] Other [ ]
On-target time excluding device tuning: 48 hrs

Total on-target time for this beam: **48** **hrs**