SAC Questionnaire - Neutron detectors - Overview

This document contains an overview of the neutron detectors available/under construction/considered. Detailed answers are found in the attached 2-page questionnaires for each of the different systems. Contained are:

- LANA (Large Area Neutron Array and possible upgrade/extension)
- MoNA-LISA (Modular Neutron Array and its upgrade, the Large Area Multi-Institutional Scintillator Array)
- VANDLE (Versatile Array of Neutron Detectors at Low Energy)
- LENDA (Low-Energy Neutron Detector Array)
- DESCANT (DEuterated SCintillator Array for Neutron Tagging)
- 3Hen
- NERO (Neutron Emission Ratio Observer)

1) *What is the primary physics motivation and experimental capability of the proposed instrument and why is this important for FRIB science?*

Detector	Primary physics motivation	Experimental capability	Primary Reaction type
LANA	Nuclear asymmetry energy, equation of state	Liquid scintillator, fast neutron, n-γ separation	HI collision
MoNA-LISA	Structure of neutron-unbound states	Plastic scintillator, Fast neutrons	Knockout, (d,p)
VANDLE	Shell structure, r- and rp-process, weak interactions, stewardship, equation of state	Plastic scintillator, Low energy neutrons (100's keV – 10+ MeV)	(d,n), βn
LENDA	Spin-isospin response of RI, weak transition strengths for astrophysics, isovector giant resonances	Plastic Scintillator, ~100 keV-5 MeV	(p.n)
DESCANT	Nuclear structure, nuclear reactions, β-delayed neutrons	Liquid scintillator, fast neutron ~100's of keV – ~10 MeV range, high-granularity, 70 cells, n-γ discrimination	Neutron evaporation, β-delayed neutrons,
3Hen	absolute Iβn for low energy βn-emitters, discoveries of new βn- and β2n-emitters, T1/2 for new n-rich isotopes, nuclear structure, r-process, processes in nuclear fuels	high granularity and efficiency (77+-2% for ~ kev for 1 MeV neutrons), 74 3He tubes,	decay spectroscopy of beta-delayed neutron emission
NERO	Measurement of beta delayed neutron emission branching for nuclear structure and r-process. Reaction studies with low-energy neutrons	Efficiency of 40% up to 1 MeV, high efficiencies for up to few MeV. No thresholds, insensitive to other radiation	decay spectroscopy of beta-delayed neutron emission

2) *What are the unique capabilities of this device that are not available in existing equipment? Is this instrument stand alone or is it to be used (solely or partially) in conjunction with other instruments. Could it be used at NSCL or other laboratories before FRIB?*

Detector	Unique Capabilities	(S)tandalone/ (C)onjuction/ (B)oth	NSCL/other lab.
LANA	n-γ separation, fast neutrons	C (AT-TPC, HiRA, other particle detectors)	NSCL
MoNA-LISA	High detection efficiency for fast neutrons	C (e.g. Sweeper/ HRS, Caesar)	NSCL

VANDLE	Adaptable, few 100 keVs-10+ MeV,low threshold (100 keVee), timing resolution fraction of ns	C (external TOF start, recoil separator, gamma detector)	HRIBF (other possible)
LENDA	Adaptable configuration, 100 keV-5 MeV, low threshold (~26 keVee), timing resolution ~500 ps	C (spectrometer e.g. S800/HRS)	NSCL (others possible)
DESCANT	High efficiency, high granularity, digital signal processing, neutron energy information from pulse height and TOF	C, with γ-ray spectrometer, recoil spectrometer, β-detector	TRIUMF, others possible
3Hen	high efficiency and granularity, digital signal processing	C, e.g., with A1900	HRIBF, NSCL,FRIB
NERO	High efficiency, large inner cavity to add additional equipment such as segmented active stopper	C, with implantation and β detection system	NSCL, GSI others possible

3) *Describe the instrument in some detail – how does it meet the scientific requirements and what are the (estimated) performance specifications? Be brief but as detailed as you can. Is the design fixed or are multiple options still being discussed and encouraged?*

Detector	Description	Alternatives studied?	Design fixed?
LANA	Liquid Scintillator walls, position sensitivity (horizontal: bars with readout at both ends, vertical: segmented), Fast Neutrons. Status: Relatively old (parts will need replacement/ maintenance), difficult to move. Future: Upgrade/Alternative needed	Detector like MoNA could be suitable	Existing LANA is fixed, future upgrade/alternative not yet fixed.
MoNA-LISA	Plastic Scintillator Bars: 200 x 10 x 10 cm^3 (MoNA 144 + LISA 144), position sensitivity, neutron ToF. MoNA is used at NSCL in conjuction with Sweeper. Usually 9 walls of 16 bars each. Optimized for 50–200 MeV neutrons. LISA is under construction. Funded by MRI.		Detector module design is fixed, but the array can be configured.
VANDLE	Plastic scintillator bars: ~100x(5x5x200cm) + ~100x(3x3x60cm), position sensitivity (segmentation and readout at end of each bar), 100's keV -10 MeV neutrons Status: Under construction, initially optimized for (d,n) and βn studies Future: Other configurations easily achieved, could be combined with LENDA to improve low-energy capability	Liquid scintillator studied, lower efficiency and n-γ separation will not work below ~500 keV.	Detector components fixed, but setup is highly adaptable.
LENDA	Plastic scintillator bars: 24x(2.5x4.5x30cm), position sensitivity (segmentation and readout at end of each bar), ~150 keV-5 MeV Neutrons Status: Constructed, optimized for (p,n) experiments in inverse kinematics with fast beams Future: Doubling solid angle is cost effective, could also be combined with VANDLE to achieve higher neutron energies and increase solid angle. Use for (d,n) and βn studies is considered.	Liquid scintillator studied, lower efficiency and n-γ separation will not work below ~500 keV.	Detector components fixed, but setup is highly adaptable.
DESCANT	70 deuterated benzene cells, designed for spherical shell with 50cm TOF to front face. Cells are tapered hexagonal shaped containers ~ 2000 cc in volume. Cells are 15 cm depth, 5" PMTs with anode directly to 1GHz wave form digitizers with on-board processing. Modularity allows for flexible configurations. Cell designed for close packed configuration to cover ~1.1π sr.	Normal scintillator studied, differences in efficiency small over energy range < 10 MeV.	Device funded, prototype delivery imminent. Demonstrated physical properties with

		Limited pulse height information compared with deuterium.	smaller test detectors.
3Hen	74 3He tubes at 10 atm, 2-foot long, efficiency reaching nearly 80% up to 1 MeV, over 50% for 5 MeV neutrons	best in class	design can be modified (e.g., new moderator)
NERO	60 BF_3 and ^{3}He gas counters (multihit) embedded in PE moderator, Efficiency 40% (<1 MeV), >20% (<5 MeV)		Device exists

4) What is the current stage of development of your project?

Detector	Status
LANA	Use of neutron arrays for EOS studies at FRIB is being discussed. Preliminary designs for auxiliary neutron arrays are in planning stage.
MoNA-LISA	MoNA has been used for experiments since 2003. LISA is under construction, bars are ordered, electronics modules already purchased. Modules will be built at the individual institutes during summer 2010 and be brought to NSCL for final assembly of the array.
VANDLE	Prototype elements assembled and characterized. Subset of system (~20 bars) will be tested 2010, stage-wise completion of full array 2010-2012
LENDA	Detector constructed, first experiments soon at NSCL
DESCANT	Fully funded; prototype delivery imminent
3Hen	fully funded, commissioning experiments likely in 2010-2011 at HRIBF
NERO	Device exists and ready for use

5) What is the approximate cost of the project: discuss possible sources of funding.

Detector	Costs	Funding source
LANA	For new array: <$500K	Possibly through NSF MRI
MoNA-LISA	already funded	NSF MRI
VANDLE	$700K (hardware only)	NNSA Academic Alliance
LENDA	$250K (hardware & labor)	NSF
DESCANT	$900k detector cells; $150k electronics, frame (TRIUMF) $300k. Dedicated, facility-specific frame for NSCL/FRIB would require separate funding	Canadian Foundation for Innovation, Ontario Research Fund, TRIUMF
3Hen	$ 50 K for adapting to the NSCL/FRIB conditions	funded at HRIBF-ORNL, further costs possibly DOE or other source
NERO		

6) Please provide a brief list of collaborators and institutions. Spokesperson(s) provide contact info.

Detector	Collaboration	Contact
LANA	NSCL (B. Tsang, B. Lynch), WMU (M. Famiano), IUCF (R. de Souza, S. Hudan), WUSTL (L. Sobotka, R. Charity), TAMU (S. Yenello)	M. Famiano (WMU) Michael.famiano@wmich.edu
MoNA-LISA	NSCL (Thoennessen, Baumann, Spyrou), Hope (DeYoung, Peaslee), CMU (Finck), IUSB (Hinnefeld), Westmont (Rogers), FSU (Tabor),	M. Thoennessen (NSCL) thoennessen@nscl.msu.edu P. DeYoung (Hope) deyoung@hope.edu

	Concordia (Luther), Wabash (Brown), Gettysburg (Stephenson), Rhodes (Meyers), Ohio Wesleyan (Kaye), Augustana (Frank), WMU (Pancella)	
VANDLE	Rutgers U., ORAU, ORNL, U. Tenn., CO School of Mines, LSU, Tenn. Tech., MSU.	J. Cizewski (Rutgers U.) Cizewski@physics.rutgers.edu W. Peters, ORAU wapeters@nuclearemail.org
LENDA	NSCL Charge-Exchange group	R. Zegers zegers@nscl.msu.edu
DESCANT	Guelph (P. Garrett, C. Svensson), TRIUMF, Colorado School of Mines (Sarazin), Montreal (J.-P. Martin)	P. Garrett (Guelph) pgarrett@physics.uoguelph.ca
3Hen	ORNL, UTK (Grzywacz), Mississippi State (Winger), LSU (Zganjar)	K.P. Rykaczewski rykaczewskik@ornl.gov
NERO	A. Aprahamian (Notre Dame), M. DelSanto(NSCL), K.-L. Kratz (University of Mainz), G. Lorusso (NSCL), F. Montes (NSCL), P. Reeder (formerly at PNNL), J. Pereira (NSCL) B. Pfeiffer (GSI), K. Smith (NSCL), H. Schatz (MSU/NSCL)	Fernando Montes, montes@nscl.msu.edu

7) *Please can you outline how your collaboration has been developing your project and how you are growing your collaboration (How many meetings? Participants?, Circular mailings? Have you a web-site?)*

Detector	Development
LANA	Is part of a larger effort for studies of EOS, collaboration meeting monthly, information disseminated through a website. International collaborators for the full project (i.e. including other experimental devices) from Europe, Japan
MoNA-LISA	Weekly meetings through video conference; annual retreat; four new members were added for the LISA project; http://www.cord.edu/dept/physics/mona/; http://mona-collaboration.blogspot.com/
VANDLE	Monthly meetings via video conference and in person, new collaborators welcome, http://vandle.oit.utk.edu/vandlewiki
LENDA	Weekly meetings, implementation (but not construction & design) for (p,n) experiments involves collaboration from GSI and RIKEN/U. Tokyo. Website: http://groups.nscl.msu.edu/charge_exchange/public/experiments/pn_inverse.htm
DESCANT	Part of the TIGRESS collaboration; bi-annual meetings with TIGRESS collaboration
3Hen	proposal to DOE followed by the funding via the HRIBF capital funds and by UTK contribution via NNSA grant, web page at UTK
NERO	

8) *Did you consider alternative designs? What alternatives were considered? How did you arrive at a final design?*

Detector	Alternatives/decision
LANA	Upgrades considered could be like MoNA or existing LANA. MoNA is more portable, but LANA has n-γ discrimination capability, which is important in certain cases.
MoNA-LISA	Smaller module cross section was considered; liquid scintillator was considered
VANDLE	Based on development of other systems, other options were investigated (see 3), but plastic scintillator is superior. Geometry tailored to energy range.
LENDA	Based on development of other systems, other options were investigated (see 3), but plastic

	scintillator is superior. Geometry tailored to energy range.
DESCANT	Normal scintillator considered; different configurations of cells
3Hen	based on the history of earlier 3He detectors developments and collaboration with local ORNL experts, UTK and UNIRIB collaborators (like S. Liddick, now NSCL)
NERO	

9) *What existing equipment exists in the US Community that has similar goals and characteristics, even if inferior in performance.*

Detector	Existing equipment with similar capabilities
LANA	MoNA, but it has no n-γ discrimination capability
MoNA-LISA	LANA has lower detection efficiency but n-γ discrimination capability.
VANDLE	LENDA is aimed at lower energy neutrons, MoNA/LANA is aimed at higher energies.
LENDA	VANDLE is aimed at slightly higher energy neutrons, MoNA/LANA at much higher energy neutrons
DESCANT	VANDLE, LENDA, but with n-γ discrimination, neutron energy via pulse height
3Hen	NERO, but its efficiency is lower
NERO	3Hen, it has higher efficiency but smaller cavity.

Collaboration Questionnaire -- Large Area Neutron Array (LANA)

To get firmer ideas about instrument packages that will be proposed at the FRIB Workshop, Feb, 20-22, 2010, we request each collaboration to fill in the following questionnaire. These should be e-mailed to Kim Lister (Lister@anl.gov) and copied to Brad Sherrill at (Sherrill@frib.msu.edu) and Rick Casten (Rick@riviera.physics.yale.edu) *no later* than Feb 12, 2010. The recommended **length** is **2 pages**, plus two additional figures. One figure should present the instrument and the other should indicate its location, size, etc on the floor at FRIB by using the floorplan template.

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1) What is the primary physics motivation and experimental capability of the proposed instrument and why is this important for FRIB science?

   The nuclear asymmetry energy is of great importance in that it is directly relevant to the nearly every macroscopic property neutron stars. Several observables are proposed to study this energy. The observables of interest may gain or lose sensitivity with the density studied. At higher densities (thus higher beam energies), sensitivity to pion production in nuclear reactions may be most relevant, though isotopic observables are relevant at all energies. In particular, neutron-proton emission is thought to be the most sensitive isotopic observable. For this reason, high sensitivity to neutrons in reactions of varying asymmetry. Large area liquid scintillator detectors, despite their low efficiency are most useful in distinguishing emitted neutrons and from photons and protons. For this reason, the Large Area Neutron Array (LANA) remains a viable and useful option in studies relevant to the nuclear EOS.

   Additionally, as an auxiliary detector to e.g., the AT-TPC, it is a powerful tool for reactions of astrophysical interest such as (α,n) reactions at astrophyisically interesting energies.

2) What are the unique capabilities of this device that are not available in existing equipment? Is this instrument stand alone or is it to be used (solely or partially) in conjunction with other instruments. Could it be used at NSCL or other laboratories before FRIB?

   The LANA in particular is currently the only neutron array with n-γ discrimination, and thus extremely useful in studies in which photon scattering may contaminate high-resolution neutron measurements. A major drawback of this array is that its portability is somewhat prohibitive. Thus, its ability to be used in conjunction with other detectors (such as the AT-TPC) is also limited. For this reason, additional neutron detection capabilities at the NSCL/FRIB would be desirable. Position sensitivity to within 10 mrad is important and quite technically feasible, as is a large solid angle coverage.

   While the currently available device is acceptable, its major drawbacks include its relative permanence in location and its age. Many of the components will very soon require replacement or maintenance.

3) Describe the instrument in some detail – how does it meet the scientific requirements and what are the (estimated) performance specifications? Be brief but as detailed as you can. Is the design fixed or are multiple options still being discussed and encouraged?

The detector in question is not new and is described extensively in the literature (cf. Zecher et al. Nucl. Instr. & Meth. Phys. Res. A 401, 329 (1997)). A detector of similar proportions to the existing LANA or the MoNA array would be extremely useful. Of particular importance are the following:

- Position sensitivity obtained via laterally spaced bars with PMT detectors on each end.
- Neutron-gamma discrimination obtained via the use of scintillator liquid.
- Large solid angle coverage. In a single experiment, it is generally desirable to cover all angles between 0 and 60^{o} and possibly more.
- Portability: Ideally, moving the detector from one part of the laboratory to another with little effort is desirable.
- Higher efficiency: Generally higher than LANA would be nice, but this would be achieved either through multiple elements or larger elements in the existing liquid design. Efficiencies exceeding 25% would be desired.

If a new auxiliary neutron detector is constructed, multiple design options would be discussed.

4) What is the current stage of development of your project?

The use of neutron detector arrays in the existing EOS program at FRIB is still being discussed and preliminary designs for auxiliary neutron arrays is still in the planning phases. Currently, much of the focus within the collaboration is toward the AT-TPC. However, the use of neutron detectors in future experiments is still being discussed.

5) What is the approximate cost of the project: discuss possible sources of funding.

Very likely, the cost of a large array neutron detector for these purposes will not exceed $500K. Funding for an addition device at the FRIB facility will likely come from NSF MRI funding if construction of an additional device is thought to be necessary.

6) Please provide a brief list of collaborators and institutions. Spokesperson(s) provide contact info.

- NSCL
    i. William Lynch
    ii. Betty Tsang
- WMU
    i. Michael Famiano, michael.famiano@wmich.edu
- IUCF
    i. Romualdo de Souza
    ii. Sylvie Hudan
- WUSTL

i. Lee Sobotka
ii. Robert Charity

- TAMU
    i. Sherry Yenello

7) Please can you outline how your collaboration has been developing your project and how you are growing your collaboration (How many meetings? Participants?, Circular mailings? Have you a web-site?)

    The collaboration has seen tremendous progress in the past year with a major DOE grant. We are currently planning with an international component. Informally, we have been meeting roughly monthly, and information is disseminated via an updated web page. Currently, the collaboration spans several institutes in Europe, Japan, and the USA.

8) Did you consider alternative designs? What alternatives were considered? How did you arrive at a final design?

    The major designs considered for this include both MoNA and LANA. Both designs can work well for various applications. While MoNA may be more portable than LANA, the neutron-gamma discrimination of LANA is extremely important in some cases. It presents the most compact type of design for its purpose.

9) What existing equipment exists in the US Community that has similar goals and characteristics, even if inferior in performance.

    MoNA is currently the most similar, though it suffers from the fact that it cannot produce discriminate between neutrons and protons. Discrete arrays of neutron detectors would also provide similar results at a much larger cost.

Collaboration Questionnaire – MoNA - LISA

To get firmer ideas about instrument packages that will be proposed at the FRIB Workshop, Feb, 20-22, 2010, we request that each collaboration to fill in the following questionnaire. These should be e-mailed to Kim Lister (Lister@anl.gov) and copied to Brad Sherrill at (Sherrill@frib.msu.edu) and Rick Casten (Rick@riviera.physics.yale.edu) *no later* than Feb 12, 2010. The recommended **length** is **2 pages**, plus two additional figures. One figure should present the instrument and the other should indicate its location, size, etc on the floor at FRIB by using the attached floor plan template.

MoNA – LISA neutron detector array

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1) What is the primary physics motivation and experimental capability of the proposed instrument and why is this important for FRIB science?

   The existing Modular Neutron Array (MoNA) and the currently being constructed Large Area multi Institutional Scintillator Array (LISA) will be used for measurements of neutron-unbound states.

   MoNA and LISA will be combined as a very large area, high efficiency neutron detector array. With the large detector volume, these arrays are well-suited to detect neutrons with high efficiency at energies that will be available at FRIB.

2) What are the unique capabilities of this device that are not available in existing equipment? Is this instrument stand alone or is it to be used (solely or partially) in conjunction with other instruments. Could it be used at NSCL or other laboratories before FRIB?

   MoNA is existing and has been used in a successful experimental program at NSCL since 2003.

   MoNA, as well as MoNA-LISA, requires a sweeper dipole magnet and charged particle detectors in order to provide neutron-fragment coincidence data for an invariant mass analysis of the unbound state that is to be studied.

3) Describe the instrument in some detail – how does it meet the scientific requirements and what are the (estimated) performance specifications? Be brief but as detailed as you can. Is the design fixed or are multiple options still being discussed and encouraged?

   - MoNA's and LISA's design is fixed.
   - MoNA and LISA are modular arrays and can be arranged in varying configurations.
   - Each array consists of 144 detector modules.
   - Each detector module consists of 10 cm by 10 cm by 200 cm plastic scintillator and two photomultiplier tubes to detect the scintillation light.
   - Each detector module offers sub-nanosecond timing and roughly 7 cm position resolution along the module.

4) What is the current stage of development of your project ?

MoNA is completed; LISA is funded by an MRI grant and is currently in the procurement phase of the project, with the assembly phase starting in the spring of 2010.

5) What is the approximate cost of the project: discuss possible sources of funding.

MoNA and LISA both are funded by MRI grants of the NSF.

6) Please provide a brief list of collaborators and institutions. Spokesperson(s) provide contact info.

N. Frank, Augustana College, Rock Island, IL 61201
J. Finck, Central Michigan University, Mount Pleasant, MI 48859
B. Luther, Concordia College, Moorhead, MN 56562
S. L. Tabor, Florida State University, Tallahassee, FL 32306
S. Stephenson, Gettysburg College, Gettysburg, PA 17325
P. A. DeYoung, G. F. Peaslee, Hope College, Holland, MI 49423
J. Hinnefeld, Indiana University South Bend, South Bend, IN 46634
T. Baumann, A. Spyrou, M. Thoennessen,
Michigan State University, East Lansing, MI 48824-1321
R. Kaye, Ohio Wesleyan University, Delaware, OH 43015
D. M. Brittingham, Rhodes College, Memphis, TN 38112
J. Brown, Wabash College, Crawfordsville, IN 47933
P. V. Pancella, Western Michigan University, Kalamazoo, MI 49008
W. Rogers, Westmont College, Santa Barbara, CA 93108

7) Please can you outline how your collaboration has been developing your project and how you are growing your collaboration (How many meetings? Participants?, Circular mailings? Have you a web-site?)

- Weekly meetings/video conferences
- Annual collaboration retreat
- Web site: http://www.cord.edu/dept/physics/mona/
- Blog: http://mona-collaboration.blogspot.com/

8) Did you consider alternative designs? What alternatives were considered? How did you arrive at a final design?

Adding steel converters can enhance detection efficiency of neutrons above 100 MeV, but this is strongly threshold dependend and not yet employed.

9) What existing equipment exists in the US Community that has similar goals and characteristics, even if inferior in performance.

Large Area Neutron Array (LANA, formerly known as NSCL Neutron Walls), lower detection efficiency, but gamma discrimination capability.

VANDLE: Versatile Array of Neutron Detectors at Low Energy

Funded by DOE, under construction, scaled implementation between 2010-2012

1) *What is the primary physics motivation and experimental capability of the proposed instrument and why is this important for FRIB science?*

Science drivers:

- VANDLE aims directly at the primary science drivers for FRIB, nuclear shell structure, the astrophysical r-process and rp-process, weak interactions, stewardship and the EOS.

Primary experimental program:

- (d,n) and βn (and βnn) measurements with neutron energy determined by time-of-flight. VANDLE aims for high efficiency and good time-of-flight resolution for low to medium energy neutrons for measurements with radioactive ion beams near the Coulomb barrier.

Other opportunities:

- Breakup reactions, neutron-tagging in fusion-evaporation and reaction studies, fission studies. The high efficiency and large solid-angle coverage with VANDLE make it a promising auxiliary detector for a variety of measurements where neutron tagging may significantly improve sensitivity for certain reaction channels.

2) *What are the unique capabilities of this device that are not available in existing equipment? Is this instrument stand alone or is it to be used (solely or partially) in conjunction with other instruments. Could it be used at NSCL or other laboratories before FRIB?*

Unique capabilities of VANDLE:

- Different element geometries allow configuration to be tailored to kinematics of reaction of interest.
- Relatively high efficiency for neutron energies over a broad range (100's keV to 10+ MeV).
- Digital signal processing is being developed to allow for extremely low thresholds (down to 100 keVee) with good timing resolution (fraction of a ns).
- VANDLE is complementary to LENDA (30 cm long bars). VANDLE cells are 60 cm and 2 m long. Combined LENDA and VANDLE capability would allow the best neutron detection capability for a wide variety of applications at Coulomb barrier energies.

Standalone or in conjuction? Pre-FRIB?

- TOF-start required from other instrument for neutron energy determination. Some possibilities are simple accelerator RF, in-beam MCP, tag from recoil separator, prompt gamma-rays, decay electrons and gamma rays.
- VANDLE could also be used as a secondary detector to increase sensitivity to reaction channels with/without neutrons.
- VANDLE is initially motivated by (d,n) and βn measurements at the HRIBF, but VANDLE is portable and could be advantageous for experiments now at the NSCL and other facilities, and for FRIB in the future.

3) *Describe the instrument in some detail – how does it meet the scientific requirements and what are the (estimated) performance specifications? Be brief but as detailed as you can. Is the design fixed or are multiple options still being discussed and encouraged?*

- Basic cell geometry is fixed to be plastic scintillator in 5x5x200cm and 3x3x60cm bar sizes.
- Approximately 100 bars in each geometry have been funded and are under construction.
- Support structures are being constructed to allow bars to be arranged in a variety of configurations.
- Two different arrangements are shown in Fig. 1 that are optimized for (d,n) and βn studies.
- Other configurations are possible and can be implemented for minimal cost.
- Other materials/geometries were investigated (most notably liquid scintillator bars). This led us to two different cell sizes to increase efficiency for lower/higher energy neutrons. We found efficiency for liquid scintillator to be lower (lower light output) and that pulse-shape discrimination was ineffective for energy deposition lower than about 500 keV.

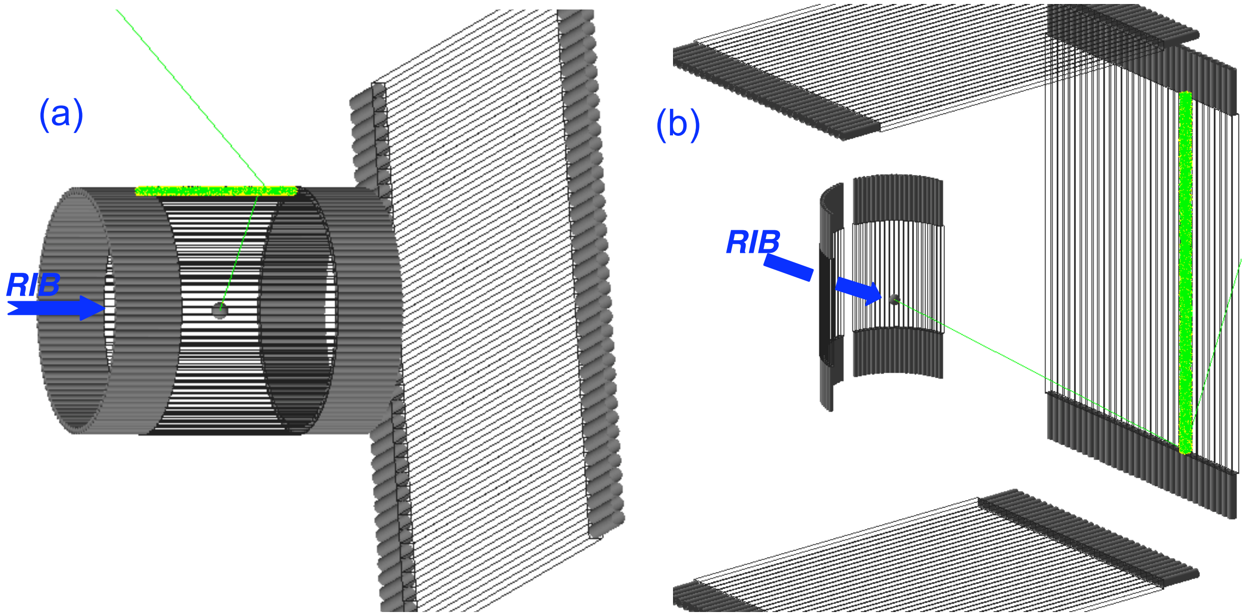

Fig. 1. Illustration of VANDLE implementations from a GEANT4 simulation in configurations been for (a) βn studies and (b) the (d,n) neutron transfer reaction. One wall is not shown for clarity.

4*) What is the current stage of development of your project?*

- Prototype bars have assembled and characterized.
- MiniVANDLE (consisting of about 10 bars in each geometry) is currently being assembled and will be tested in-beam in summer of 2010.
- VANDLE construction is to be completed in stages between 2010 and 2012.

5) What is the approximate cost of the project: discuss possible sources of funding.

- Current project (funded by NNSA Academic Alliance) includes 100 bars in each size.
- Cost (hardware only) is about $3500/bar, dominated by PMT's and electronics (100MHz Pixie).

6) Please provide a brief list of collaborators and institutions. Spokesperson(s) provide contact info.

- Project is led by Jolie Cizewski, Rutgers Univ. (PI) (contact: cizewski@physics.rutgers.edu) and William Peters, ORAU (wapeters@nuclearemail.org).
- Collaborators include ORNL, Univ. Tenn., CO School of Mines, LSU, Tenn Tech., MSU.

7) Please can you outline how your collaboration has been developing your project and how you are growing your collaboration (Meetings? Participants? Circular mailings? Have you a web-site?)

- Collaboration holds regular (~monthly) meetings via video conference and in person.
- New ideas and collaborations are welcome.
- Website: http: vandle.oit.utk.edu/vandlewiki

8) Did you consider alternative designs? What alternatives were considered? How did you arrive at a final design?

- VANDLE builds upon substantial previous developments of other neutron detector arrays, e.g. MoNA, LENDA. Other options were investigated (see item 3 above), but plastic scintillator was found to deliver superior performance and ease of implementation. Geometry of array was tailored to energy range of interest.

9) What existing equipment exists in the US Community that has similar goals and characteristics, even if inferior in performance.

- VANDLE is optimized for higher energy neutrons than LENDA and lower energy neutrons than MoNA. The different element geometries allow for efficient neutron detection over a wide range. Increasing the number of elements (particularly for LENDA and VANDLE) could significantly improve sensitivity and decrease running time.

LENDA

LENDA: Low-Energy Neutron Detector Array

LENDA is funded by NSF and was constructed at the NSCL. First experiments expected in fall 2010.

1) *What is the primary physics motivation and experimental capability of the proposed instrument and why is this important for FRIB science?*

Primary objective: Studies of (p,n) charge-exchange reactions at intermediate energies in inverse kinematics motivated by the following goals:

a) To study the spin-isospin response of asymmetric systems with the aim to investigate changes in the shell structure of nuclei away from stability.
b) To measure weak transitions strengths in unstable nuclei of relevance for astrophysical phenomena, in particular late stellar evolution.
c) To study isovector giant resonances and their relation to macroscopic properties of nucleonic matter away from stability and the reduction of uncertainties in the description of the isovector component of the nucleon-nucleon interaction.

Other opportunities under consideration:

1) Proton transfer (d,n) reactions in inverse kinematics at low energies.
   a) Determine thermonuclear (p,γ) direct – capture reaction rates of importance for astrophysics through the asymptotic normalization coefficient (ANC) method.
   b) Study resonance properties of (p,γ) reactions important for stellar nucleosynthesis above the proton emission threshold
2) β-delayed neutron emission experiments: studies of nuclear structure and basic decay properties of neutron-rich isotopes.

2) *What are the unique capabilities of this device that are not available in existing equipment? Is this instrument stand alone or is it to be used (solely or partially) in conjunction with other instruments. Could it be used at NSCL or other laboratories before FRIB?*

Unique capabilities of LENDA:

- Detection of neutrons with energies ranging from 0.15-4 MeV
- Neutron Detection Efficiency >25% over this energy range
- Threshold: ~26 keVee
- Position resolution: 4.5 cm (FWHM) along the bar, bars are 4.5 cm wide
- Timing resolution: ~600 ps (20 keV for E_n=200 keV with flightpath of 1 m)

For (p,n) experiments in inverse kinematics, LENDA will be **run in coincidence with a magnetic spectrometer** to detect the beam-like reaction product for the purpose of tagging the charge-exchange reaction. LENDA benefits from a liquid Hydrogen system, which is currently under construction (NSF-MRI proposal, PI: Lew Riley).

For other applications (e.g. (d,n) in inverse kinematics) LENDA would run in coincidence with other devices (to provide the trigger etc). For several of those applications, LOIs have been submitted to the NSCL PAC.

LENDA is complementary to VANDLE (60cm and 2m long bars). LENDA is aimed at detecting neutrons below 4 MeV while optimizing the detection of the lowest energy neutrons. VANDLE covers the range from several 100's keV to 10+ MeV.

3) *Describe the instrument in some detail – how does it meet the scientific requirements and what are the (estimated) performance specifications? Be brief but as detailed as you can. Is the design fixed or are multiple options still being discussed and encouraged?*

At present LENDA has two mounting frames (see Fig. 1(left) below for one such frame), which each holds up to 12 plastic scintillator bars with dimensions 4.5x2.5x30cm. Scintillation light is detected in PMTs mounted on both ends of each bar. The mounting frames are designed for (p,n) experiments in inverse kinematics (See Fig. 1(right)). For other applications, different frames might be necessary. Electronics is analog, except for FPGA used in trigger-logic.

LENDA

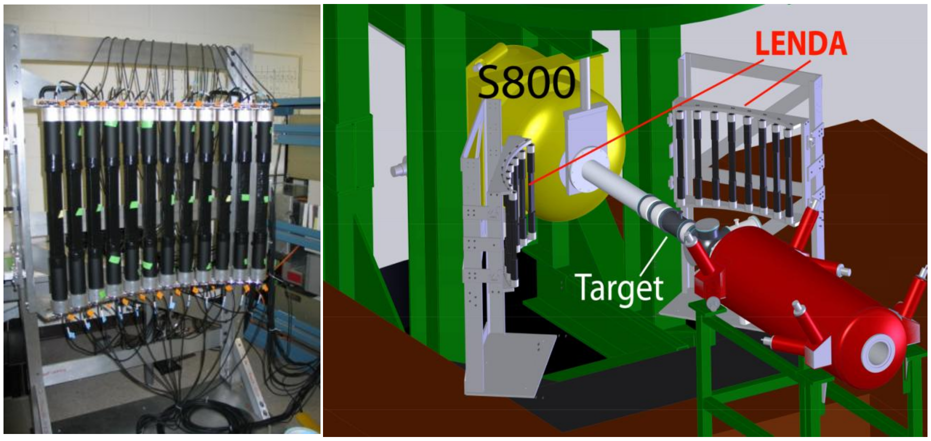

Figure 1 (left) One of the two existing mounting frames of the Low-Energy Neutron Detector Array (LENDA). (right) Schematic drawing of LENDA positioned in front of the S800 spectrometer for (p.n) experiments in inverse kinematics.

4) *What is the current stage of development of your project ?*
Construction of LENDA has been completed. First (p,n) experiments at the NSCL are expected in Fall of 2010. For other applications, new frames might have to be designed. Because the scintillator bars of LENDA are relatively small and modular, different configurations can easily be achieved.

5) *What is the approximate cost of the project: discuss possible sources of funding.*
LENDA cost about $250.000 (full array + electronics; FY2008 dollars). Increasing the solid angle by a factor of 2 (i.e. from 24 to 48 bars) would cost about $220.000 (FY 2008 dollars). It might be worthwhile to consider an increase of the solid angle for use at FRIB, since the running time of experiments could be reduced.
An attractive alternative is to combine LENDA with VANDLE: by carefully placing the bars such that LENDA covers kinematic regions where the lowest neutron energies are expected and VANDLE covers kinematic regions where slightly (60 cm bars) to significantly higher (2 m bars) neutron energies are expected. A combined LENDA-VANDLE configuration would be suitable for a wide variety of applications.

6) *Please provide a brief list of collaborators and institutions. Spokesperson(s) provide contact info.*
NSCL charge-exchange group led by Remco Zegers (zegers@nscl.msu.edu)

7) *Please can you outline how your collaboration has been developing your project and how you are growing your collaboration (How many meetings? Participants?, Circular mailings? Have you a web-site?)*
Weekly group meetings. Website: http://groups.nscl.msu.edu/charge_exchange/

8) *Did you consider alternative designs? What alternatives were considered? How did you arrive at a final design?*
We have considered several designs and types of neutron detectors. The present design was chosen because we can simultaneously achieve good neutron detection efficiency, energy (timing) resolution and angle (position resolution).

9) *What existing equipment exists in the US Community that has similar goals and characteristics, even if inferior in performance.*
VANDLE is based on similar principles, but is optimized for higher energy neutrons. MoNA is another neutron detector array employing plastic scintillators, but meant for fast (>10 MeV) neutrons. NSCL has two neutron walls that utilize liquid scintillators, and is meant for fast neutrons (>10 MeV) neutrons.

Collaboration Questionnaire – DESCANT

To get firmer ideas about instrument packages that will be proposed at the FRIB Workshop, Feb, 20-22, 2010, we request that each collaboration to fill in the following questionnaire. These should be e-mailed to Kim Lister (Lister@anl.gov) and copied to Brad Sherrill at (Sherrill@frib.msu.edu) and Rick Casten (Rick@riviera.physics.yale.edu) *no later* than Feb 12, 2010. The recommended **length** is **2 pages**, plus two additional figures. One figure should present the instrument and the other should indicate its location, size, etc on the floor at FRIB by using the attached floor plan template.

1) What is the primary physics motivation and experimental capability of the proposed instrument and why is this important for FRIB science?

Fusion evaporation reactions leading to neutron-rich systems will produce copious number of evaporation neutrons, requiring a high-efficiency detector system capable of discriminating multiple scattering of neutron from true higher-multiplicity events. Coupled to high efficiency gamma-ray spectrometer, DESCANT will allow a program of in-beam gamma-ray spectroscopy with neutron-rich beams.

High granularity of DESCANT detectors, coupled with ability to discriminate against multiple scattered neutron events, enabled with the over-determination of the neutron energy via the pulse height from the deuterated scintillator and TOF, will allow two-neutron correlations to be performed to small opening angles between neutrons, important for neutron spectroscopy of very neutron-rich, halo nuclei.

2) What are the unique capabilities of this device that are not available in existing equipment? Is this instrument stand alone or is it to be used (solely or partially) in conjunction with other instruments. Could it be used at NSCL or other laboratories before FRIB?

DESCANT will use deuterated beneze as a liquid scintillator medium. The use of the deuterium in the recoil medium takes advantage of the asymmetric n-d scattering that results in a pulse height signal that has a definite peak structure that can be related to the incoming neutron energy. Combined with the neutron TOF, this gives two measures of the neutron energy. This over-determination of the neutron energy enables an efficient algorithm for rejecting multiple scattering between detector cells vs. true higher multiplicity neutron events. The C6D6 liquid scintillator offers excellent neutron-gamma discrimination, at least as well as normal hydrogen-based scintillators.

DESCANT is designed to be used in conjunction with a gamma-ray spectrometer, and has been designed for use with TIGRESS. It could be used with GRETA or GRETINA provided a frame was constructed. The DESCANT array may be transported to other facilities for campaigns, including the NSCL and FRIB.

3) Describe the instrument in some detail – how does it meet the scientific requirements and what are the (estimated) performance specifications? Be brief but as detailed as you can. Is the design fixed or are multiple options still being discussed and encouraged?

DESCANT has been designed to provide a close-packed coverage of the spherical-shell with an opening angle up to ~65 degrees. The modularity of the design allows for the removal of rings of detectors. Figure 1 shows the nominal designed layout of the detector elements. The frame constructed for TRIUMF allows for the inner-most two rings of detectors to be removed to enable the coupling with other down-stream detectors, which may include recoil-separators, Bragg detectors, PPACS, etc. The target to front-face distance is 50 cm. The cells are 15cm in thickness, with the Red, White and Blue shapes coupled to 5" PMT's and the Green shape coupled to 3" PMT's.

The anode signals will be fed directly into 1 GHz wave form digitizers custom built by J.-P. Martin at Montreal. These are designed to be integrated into the TIGRESS data acquisition system. On-board DSP will provide n-gamma discrimination, TOF, and pulse height. Options will include the read-out of full wave forms, or derived information.

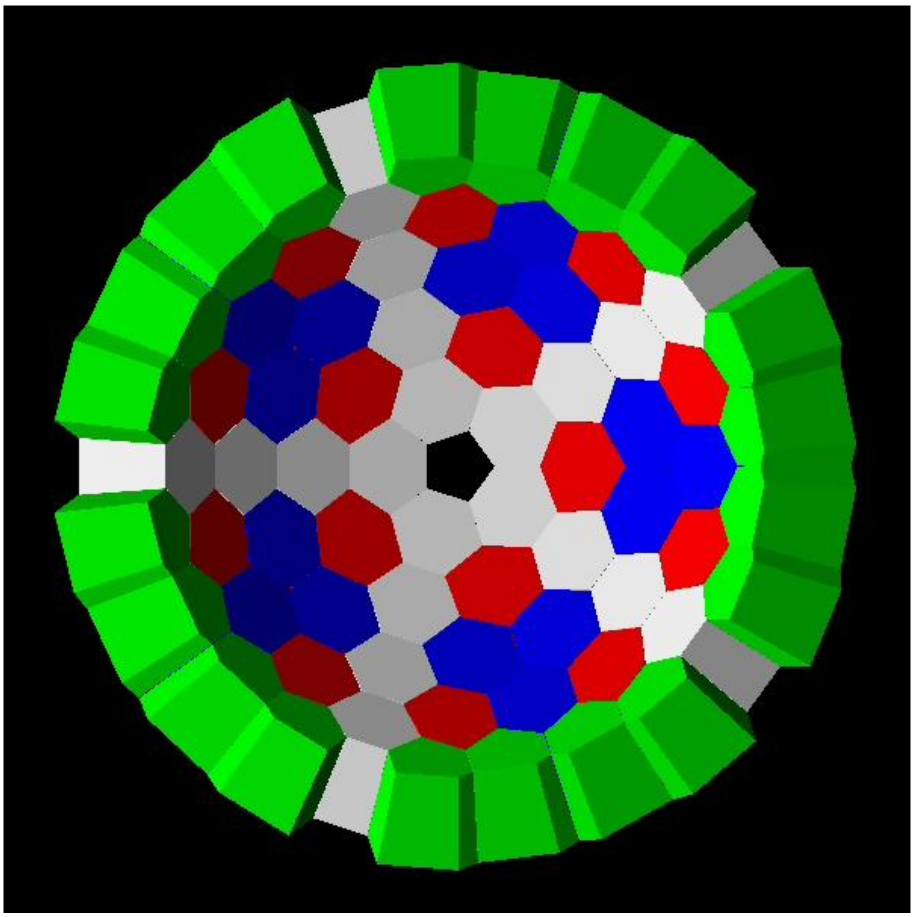

Figure 1:Arrangement of detector cells for DESCANT, as seen from the upstream position looking downstream. Four different shapes, as distinguished by their color, are used to cover the available 65.5°. The detectors subtend a total solid angle of 1.08π sr.

4) What is the current stage of development of your project ?

The project is fully funded. The delivery of the prototype detector is imminent. Once tested, production of the units will proceed rapidly with a delivery schedule of 8 units per month. The array is scheduled for completion in Spring 2011, with commissioning summer/fall 2011 at TRIUMF.

5) What is the approximate cost of the project: discuss possible sources of funding.

DESCANT is a $1.8M project, with funding of $640k from the Canadian Foundation for Innovation, $640k from the Ontario Research Fund, and an in-kind contribution of ~$300k from TRIUMF for the frame design and construction, and in-kind contributions from St. Gobain amounting to ~$200k.

6) Please provide a brief list of collaborators and institutions. Spokesperson(s) provide contact info.

P.E. Garrett (Guelph), PI and project leader pgarrett@physics.uoguelph.ca
C.E. Svensson (Guelph), G.c. Ball, G. Hackman, B. Davids (TRIUMF), J.-P. Martin (Montreal), F. Sarazin (Colorado S. of Mines) S.W. Yates, M.T. McEllistrem (Kentucky) are main collaborators. Other collaborators are R. Roy (Laval), A. Chen (McMaster), R. Kanungo, R.A.E. Austin (St. Mary's), C. Andreiou, K. Starosta (Simon Fraser).

7) Please can you outline how your collaboration has been developing your project and how you are growing your collaboration (How many meetings? Participants?, Circular mailings? Have you a web-site?)

DESCANT collaboration is tightly coupled with the TIGRESS collaboration. Bi-annual collaboration meetings are held, typically at TRIUMF.

8) Did you consider alternative designs? What alternatives were considered? How did you arrive at a final design?

An array based on normal hydrogen-based scintillator was considered, but deuterated scintillator was adopted based on superior performance. Comparisons with small-volume test cells between C6D6-based liquid (BC537) and normal fluid (BC501A) demonstrated the utility of the pulse height information for extraction of the incident neutron energy, and equal, if not superior neutron-gamma discrimination.

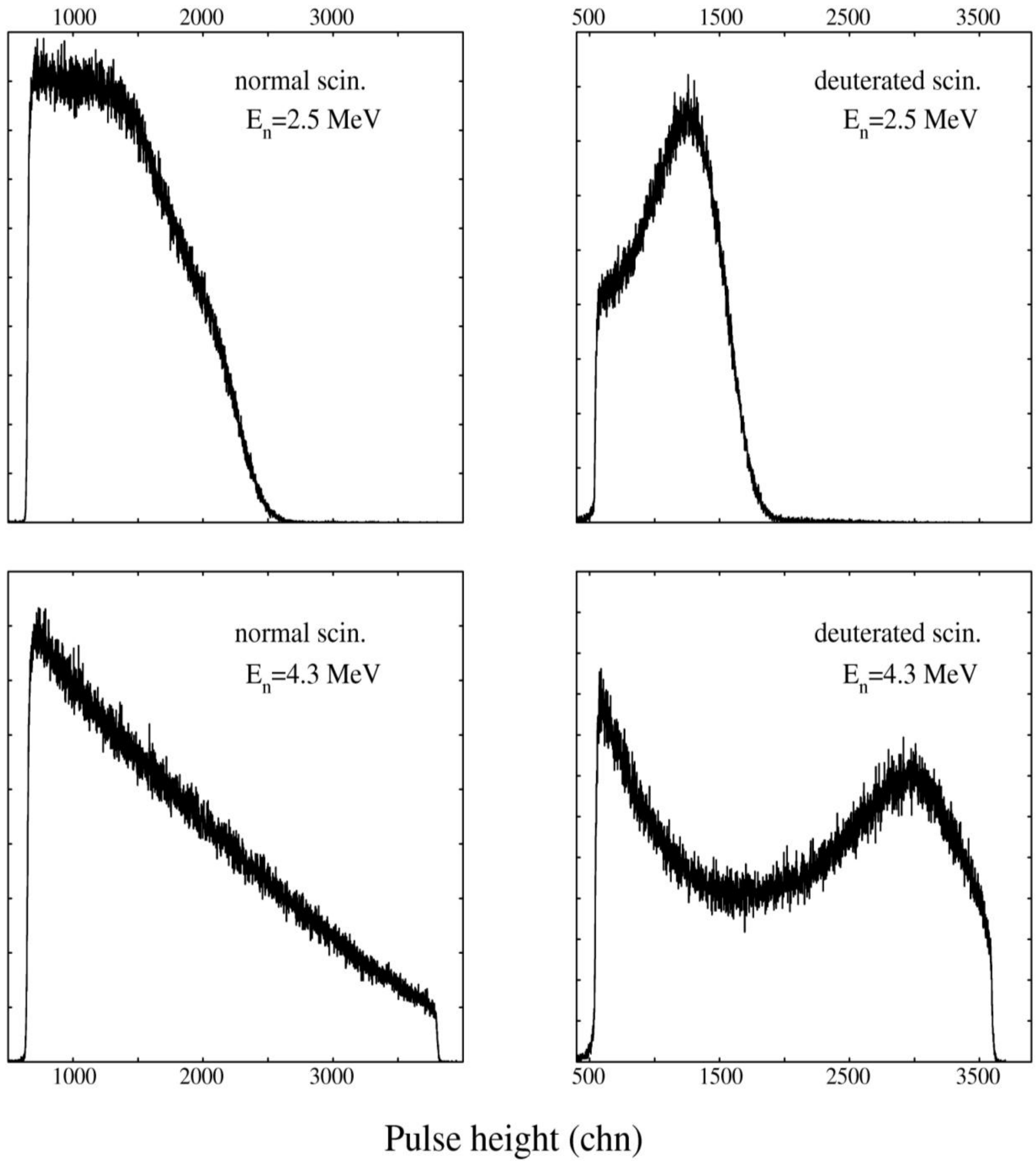

Figure 2:Pulse-height spectrum for neutron energies of 2.5 MeV (top) and 4.3 MeV (bottom) incident on a normal liquid scintillator (left) and a deuterated scintillator (right). The position of the peak in the deuterated scintillator varies as ~$(E_n)^{3/2}$.

9) What existing equipment exists in the US Community that has similar goals and characteristics, even if inferior in performance.

The VANDLE and LENDA devices appear to be designed for a similar energy range and physics goals. DESCANT allows for n-gamma discrimination and efficient algorithms for multiple-scattering vs. true n-multiplicity events.

Digital beta-delayed neutron (βn) detector 3Hen

1) *What is the primary physics motivation and experimental capability of the proposed instrument and why is this important for FRIB science?*

Primary objectives:

1) The measurements of absolute βn-branching ratio for low energy beta-delayed neutron emission (0.1-1.0 MeV).
2) The discoveries of new beta-delayed two-neutron emitters and the estimation of the β2n-branching ratio.
The measurements of beta half-life for new very neutron rich isotopes of relevance for the r-process and nuclear fuels

2) *What are the unique capabilities of this device that are not available in existing equipment? Is this instrument stand alone or is it to be used (solely or partially) in conjunction with other instruments. Could it be used at NSCL or other laboratories before FRIB?*

- 3HeN has high efficiency, of about 77+-2%, for wide neutron energy range from ~ keV to 1 MeV range, and about 50% for 5 MeV neutrons.
- High granularity (seventy four 3He tubes) and efficiency of 3Hen is perfect for the studies aiming in the discoveries of new β2n emitters and half-life measurements for weakly produced neutron rich nuclei. The 3Hen detector array including internal beta energy-loss detectors will be commissioned, efficiency-calibrated and applied to the decay studies at the HRIBF. #Hen in its HRIBF version is fully funded.
- Digital signal processing
- The further developments and/or adaptation of auxiliary beta counters and tape collector designed to fit the HRIBF needs might be needed for the experiments at FRIB (rough cost estimate about $50 K).

3) *Describe the instrument in some detail – how does it meet the scientific requirements and what are the (estimated) performance specifications? Be brief but as detailed as you can. Is the design fixed or are multiple options still being discussed and encouraged?*

The 3Hen detector array consists of seventy four 3He 2-foot long counters, of 1” and 2” diameter, at 10 atm gas pressure embedded in the barrel-like High Density Polyethylene (HDPE) moderator structure, with 90 mm diameter through hole. The inner ring of sixteen 1”-diameter tubes has position sensitive counters. High Voltage is supplied using ISEG HV cards and Wiener MPOD crate.
3Hen signals processing is based on the MESYTEC 16-channel preamplifier cards and digital electronics (100 MHz Pixie-16 modules of XIA). The system of three Single-sided Silicon Strip detector will be used in vacuum inside 3Hen providing beta energy loss signal for beta-neutron fast time correlations.
In principle, it is possible to change the HDPE structure and accommodate 3He tubes in a different geometry.

4) *What is the current stage of development of your project?*
Fully funded, commissioning experiments likely in 2010-2011 at HRIBF

5) *What is the approximate cost of the project: discuss possible sources of funding.*
Funded at HRIBF-ORNL; $50K for adapting to the NSCL/FRIB conditions, funded possibly through DOE or other source

6) *Please provide a brief list of collaborators and institutions. Spokesperson(s) provide contact info.*

- Collaboration: ORNL, UTK (Grzywacz), Mississippi State (Winger), LSU (Zganjar)
- Contacts: K.P. Rykaczewski rykaczewskik@ornl.gov

7) *Please can you outline how your collaboration has been developing your project and how you are growing your collaboration (How many meetings? Participants? Circular mailings? Have you a web-site?)*

Proposal to DOE followed by the funding via the HRIBF capital funds and by UTK contribution via NNSA grant, web page at UTK

8) *Did you consider alternative designs? What alternatives were considered? How did you arrive at a final design?*
   Based on the history of earlier 3He detectors, developments and collaboration with local ORNL experts, UTK and UNIRIB collaborators (like S. Liddick, now NSCL)

9) *What existing equipment exists in the US Community that has similar goals and characteristics, even if inferior in performance?*
   NERO, but its efficiency is lower

Collaboration Questionnaire -- Instrumentation for FRIB
Neutron Emission Ratio Observer (NERO)

Spokesperson: Fernando Montes
NSCl, Michigan State University
East Lansing, MI 48824
USA
montes@nscl.msu.edu

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1) What is the primary physics motivation and experimental capability of the proposed instrument and why is this important for FRIB science?

NERO has been primarily designed to measure beta delayed neutron emission branchings. Beta delayed neutron emission of extremely neutron rich nuclei play an important role in the astrophysical r-process as they affect the produced abundance patterns before and after neutron freeze-out and through late time infusion of fresh neutrons. Understanding of the nuclear physics of r-process nuclei is one of the major motivations for FRIB, which will have unique production capabilities for r-process isotopes. NERO could also be used for other purposes such as reaction studies, where low energy neutrons need to be detected with high efficiency.

2) What are the unique capabilities of this device that are not available in existing equipment? Is this instrument stand alone or is it to be used (solely or partially) in conjunction with other instruments. Could it be used at NSCL or other laboratories before FRIB?

This is an existing device that we wish to employ at FRIB.

NERO is a neutron long counter and shares some advantages with other devices of this type:
- high detection efficiency of low energy neutrons up to a few MeV
- constant detection efficiency of 40% out to ~1 MeV
- no energy threshold for neutron detection so total branching can be measured directly
- largely insensitive to radiation other than neutrons

Unique capabilities are:
- large inner cavity (22.8 cm diameter) provides flexibility to hold wide range of additional detection equipment such as a large, highly segmented active stopper

Use with other instruments:
For measurements of beta delayed neutron emission NERO has to be combined with an implantation and beta detection system (“decay station”). NERO is currently used with the NSCL Beta Counting Station and with other implantation detectors using Si strip detectors.

Use at existing facilities
NERO is currently used at NSCL, and use at other facilities such as GSI is planned.

3) Describe the instrument in some detail – how does it meet the scientific requirements and what are the (estimated) performance specifications? Be brief but as detailed as you can. Is the design fixed or are multiple options still being discussed and encouraged?

NERO is a neutron long counter consisting of BF3 and 3He gas counters embedded into a polyethylene moderator matrix. This is an existing device and performance parameters are well established and verified experimentally.

- Efficiency is 40% below 1 MeV and remains above 20% up to 5 MeV.
- Moderation time (average time before detection) is 40-60 μs.
- Segmented in 60 detectors, each channel has multi-hit capability, so well suited to detect multiple neutron emission.

4) What is the current stage of development of your project ?

Device exists and is ready for use.

5) What is the approximate cost of the project: discuss possible sources of funding.

N/A

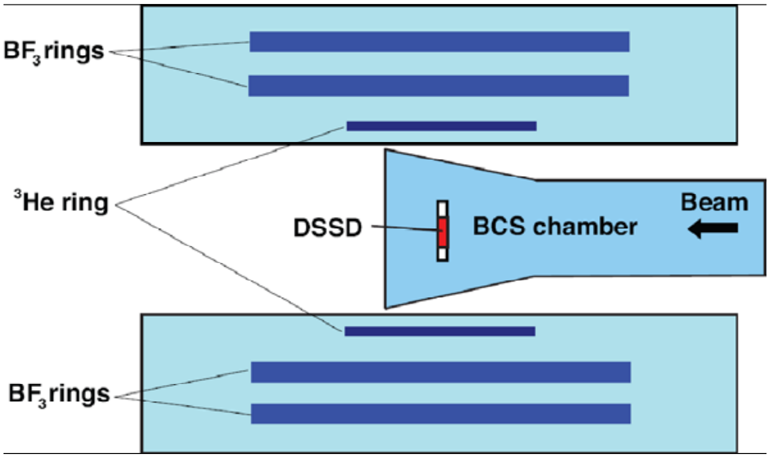
6) Please provide a brief list of collaborators and institutions. Spokesperson(s) provide contact info.

NERO is used by several different collaborations.
The current NERO core collaboration includes:
A. Aprahamian, Notre Dame
M. DelSanto, NSCL
K.-L. Kratz, University of Mainz
G. Lorusso, NSCL
F. Montes, NSCL
P. Reeder, formerly at PNNL
J. Pereira, NSCL
B. Pfeiffer, GSI
K. Smith, NSCL
H. Schatz, MSU/NSCL

7) What existing equipment exists in the US Community that has similar goals and characteristics, even if inferior in performance.

3Hen at ORNL is a newly developed neutron long counter system of similar nature, with higher efficiency but smaller cavity. Other neutron long counters probably exist.

Side view of NERO:



Front view of NERO: