Report of the FRIB Science Advisory Committee on Equipment and Equipment Proposals Presented at the FRIB Workshop

Feb. 20-22, 2010

Submitted, 10 March, 2010

FRIB Scientific Advisory Committee

Report of the FRIB Science Advisory Committee (SAC)

I Introduction

FRIB, with its large variety of beams of exotic nuclei, provides a remarkable set of linked opportunities and prospects to advance nuclear science on many fronts, ranging from nuclear structure and reactions, to nuclear astrophysics, tests of fundamental symmetries, and to societal applications in a large variety of venues. There is a large and enthusiastic community dedicated to making this endeavor a success. To have well over 250 scientists assemble on rather short notice to discuss the suite of instruments and the infrastructure planned for FRIB is in itself impressive testimony to this enthusiasm for the scientific advances that FRIB will provide.

The preparations for this Workshop began soon after it was announced with collaborations formed to plan for the equipment needed to address specific science questions. The FRIB SAC is grateful for the large amount of work the collaborations devoted to providing 2-page answers to the questionnaire distributed in advance of the Workshop. The descriptions contained in these questionnaires were of great help to the SAC in its discussions and gave a level playing field to its deliberations.

The purpose of this Report is to provide a first assessment of these instruments/collaboration plans. However, this presents several difficulties worth mentioning at the start. The first stems from the (necessary) format of the Workshop. In order to accommodate sufficient time for discussions, it was imperative to have a number of parallel sessions. As a consequence only a small fraction of SAC members could attend any given session and, therefore, much of the integrated body of knowledge within the SAC had to come from individual SAC members via indirect information transfer in subsequent SAC discussions. Secondly, the SAC was faced with attempting an evaluation of the work of many collaborations that are currently at very different stages of development. With rapid advances occurring in many areas, and with uncertainties in some cases as to the best solutions in order to address the physics, some collaborations are still evaluating suitable approaches while others are already at the stage where detailed designs exist and/or construction is about to begin.

For this reason, and by the nature of the material and the process, the committee felt that it is premature to assign specific rankings to the individual projects. Instead of presenting rankings, we provide a narrative commentary below on each of the proposals (occasionally grouping more than one together if appropriate).

It is nevertheless worth pointing out that several projects, in particular, SECAR (with JENSA), the AT-TPC, the HRS/S800 Upgrade, GRETINA / GRETA, and HELIOS, have rather concrete plans to move forward, and a generally agreed-upon approach. Some of these have rather advanced designs, and some are entering the construction phase. While certain decisions, or even final design elements, still need to be achieved for these projects, the SAC sees no evidence of significant barriers to success and no show-stoppers. Moreover, each addresses clearly defined physics questions. Other projects are at more preliminary stages of development. Some are in the process of organizing, evaluating different approaches or technologies, or planning R&D initiatives. Note that, in making the distinction in this paragraph, we have not considered the DAQ and target infrastructure categories since these efforts are not project-specific but rather have an impact on, and are being impacted by, nearly all projects.

The commentaries below briefly summarize each project, the physics to be addressed, how it intends to achieve its goals, what its present status is and, in some cases, its links to other projects. Where relevant, we then provide feedback and, often, suggestions for making future progress. In many of these cases, a common theme of the recommendations is that the separate sub-groups interested in a given topic should bind together to make a coherent effort towards a common solution, rather than pursuing largely independent paths. In fact, in a number of cases, those involved already recognize this need and are moving in an appropriate direction.

The committee stresses one crucial point: the current set of projects, while ambitious, is by no means the final one, nor should anything said below be construed as precluding new proposals and initiatives. Indeed, with the rapid advance of the science of exotic nuclei, it would be surprising if new ideas and instruments did not emerge in the coming years, and the SAC very much welcomes these.

The individual projects are themselves intertwined in many cases. As examples, neutron detectors, scintillators, and silicon arrays can be used as auxiliary detectors to address a variety of open scientific challenges. Their design and implementation therefore needs to be coordinated, both among themselves and with the instruments they will complement. As another, rather obvious, example, already alluded to above, the area of DAQ spans all projects and its standards and protocols need to be developed in a coherent and timely way. Some mechanism should be developed to advance cross-talk between collaborations.

The projects discussed in this Workshop are evolving in a national and international context of intense activity. We encourage collaborations to continue to take advantage of technical developments at other rare isotope facilities world wide, and explore possibilities of collaborations where appropriate.

The SAC notes the synergy between these proposals and the facility itself. Thus, the development of the instruments is directly linked to the capabilities of FRIB in its final design. For example, many of the instruments assume that ReA12 will be operational at FRIB and are designed for the energy regime it entails.

Lastly, the committee feels that it is essential that any explicit ranking of a set of formal proposals in the future be carried out in the context of presentations to the entire SAC.

II Evaluations

The projects below are arranged according to the general class of instrument or initiative involved. They are ordered in a way that is convenient for the discussion. **Absolutely no ordered ranking is intended, nor should one be construed.** The content of the SAC's recommendations is embodied in the narratives themselves.

SEPARATORS

A) Astrophysics Separator – SECAR

FRIB will produce many of the exotic nuclei important for astrophysical nucleosynthesis processes. These include the proton-rich nuclei essential for the rp-process that occurs on the surface of mass-accreting neutron stars in binary systems, in novae, and the recently discovered neutrino-p-process, taking place in the early ejecta of core-collapse supernovae. The recoil separator SECAR is essential to exploit the astrophysical opportunities offered by FRIB. It will allow direct measurements of the cross sections for proton and α capture reactions on relevant proton-rich nuclei available at NSCL ReA3 and FRIB. Timely completion will allow SECAR to be used at NSCL before FRIB becomes operational.

SECAR is being planned and designed by an experienced group which is studying possible designs and performing detailed ion-optics studies based on the experience at existing devices such as DRAGON at TRIUMF or the separator St. George under construction at Notre Dame. Alternative extensions and/or improvements are also being investigated. The work is being performed under a grant from the DOE.

SECAR can be used in conjunction with a novel gas target system currently developed by the JENSA collaboration for applications at HRIBF and later at ISAC. The system will at first use helium as fill gas and then later hydrogen as well. The gas target will be used to study transfer reactions in inverse kinematics, in this way allowing an indirect determination of resonance parameters for reactions important to astrophysics. The system is funded by a DOE grant. The JENSA collaboration will build a second, JINA funded, gas target at NSCL adapted to the needs at ReA3. It will offer the flexibility to choose between gas cells and jets. It will be used for an initial science program at NSCL ReA3 and will be available later for use at FRIB.

B) HRS / S800 Upgrade

The new High Rigidity Spectrometer (HRS) and the upgraded S800 high resolution spectrometer will strengthen experimental programs with fast rare ion beams produced with the in-flight method at FRIB. Both the S800 and the HRS can be coupled with SeGA, CAESAR, LENDA, GRETA and MoNA-LISA and enable a broad physics program with fast radioactive beams. The S800 spectrometer is a highly-productive spectrometer: it is used for a wide variety of experiments studying nuclear structure via fast reactions. However, the maximum rigidity of the S800 is limited to 4 Tm, and the S800 cannot accept a subset of fast radioactive beams that FRIB will provide. The new HRS concept, replacing the existing sweeper magnet, has a maximum rigidity of 7 Tm and to accept exotic nuclei close to the neutron-drip line that the S800 spectrometer cannot handle. In addition, the HRS is designed with a large momentum/angular acceptance and a reasonable momentum resolution in order to accommodate several types of experimental programs. The idea of using a movable quadrupole-triplet in the HRS is interesting, and creates an additional target section just in front of the dipole to give a large angular acceptance for the MoNA-LISA setup. The final design of the HRS should involve other considerations such as, for example, the excitation energy coverage for MoNA-LISA, and the total flight path length required to achieve a reasonable mass resolution in particle identification. The design concept for the HRS should be finalized as soon as practical since it affects the beam line layout and other infrastructure issues.

C) Separators for reaccelerated beams (ISLA, RMS-like, Gas-filled)

Particle separators are essential tools for a broad range of physics issues to be addressed with reaccelerated beams, ranging from nuclear structure studies at the limits of nuclear existence, to measurements of importance for nuclear astrophysics, to applications. At FRIB, such instruments will be used most often to provide identification of the heavy, beam-like reaction products, to separate a specific reaction product for subsequent decay investigations, or as a tool to study reaction dynamics. They need to be suitable for use with very weak beams. In most instances, such devices will be used in conjunction with other detectors placed around the target, at the focal plane, or at both locations.

At this point, it is not clear that a single separator can address all the needs of the FRIB physics program. However, in order to assess this, it is important for the community to determine what the most important reaction mechanisms are for the near-term scientific program at FRIB. It is not at all clear that fusion-evaporation reactions, the only mechanism for which examples were presented at the Workshop, will be the reactions of choice for the study of neutron-rich exotic nuclei. Transfer and complex multi-nucleon transfer reactions may prove more useful to reach nuclei with large neutron excess.

The three approaches to an FRIB separator discussed at the Workshop appeared to be dedicated to specific "niche" issues. The ISLA spectrometer provides limited physical mass separation and may well be unable to tolerate the high count rates that are likely to occur for reactions producing nuclei closer to stability. The SUPERB spectrometer appears to be optimized for the detection of evaporation residues and seems to be less efficient for nuclei produced by other types of reactions. A gas filled spectrometer does not provide mass selection and appears to be optimal primarily for superheavy element research, a program with great scientific potential, but whose contributions to day-one FRIB research need to be evaluated.

At this time all interested groups should continue their design efforts, but in the context of a single, strong, collaborative effort. The collaboration should identify and prioritize the reaction mechanisms likely to provide the broadest range of scientific opportunities at FRIB. They should then explore the design for one or more separators that will optimize their realization. One recommendation is to develop a range of benchmark experiments to compare different separator options.

DETECTORS/INSTRUMENTS

D) GRETINA – GRETA – Digital Gammasphere

GRETINA is a unique national γ-ray detector system designed to study the structure and properties of atomic nuclei. Its improved position resolution and high efficiency make it an ideal array to study exotic nuclei, especially those produced with fast beams. GRETINA uses the concept of γ-ray tracking to achieve a factor of 10- to 30-fold improvements in γ-ray resolving power over existing systems. A large fraction of FRIB experiments will require γ-ray detection and GRETINA will allow FRIB to extend its science reach. Its higher efficiency will overcome the low intensity of many exotic radioactive beams. The device is in the construction stage. The scheduled completion date is February 2011. The total equipment cost is $17M and it is fully funded as a MIE by DOE's Office of Nuclear Physics. The community of scientists around GRETINA is very well organized. There are 5 working groups focusing on the physics case, auxiliary detectors, electronics, software, and detector development. GRETINA is planned to be used at the NSCL, HRIBF and ATLAS. GRETA is the extension of GRETINA from 1-π solid angle coverage to 4-π and has been strongly endorsed in the 2007 NSAC Long Range Plan. As more detectors become available for GRETA, they could be incorporated in GRETINA and used at other facilities before FRIB. The likely source of funding for GRETA is DOE's Office of Nuclear Physics. Provision for and flexibility to incorporate auxiliary detectors in GRETA/GRETINA is a necessary component of planning going forward. Finally, a project is currently underway to digitize Gammasphere signals where compatibility with GRETINA is ensured by using the same digitizer technology and software.

E) AT-TPC

Two working groups focused on the physics to be carried out with the active-target time projection chamber—the AT-TPC. With funding from an NSF MRI, the collaboration is now developing an AT-TPC for use at the NSCL. The device will carry out a broad science program with reaccelerated and fast beams addressing questions in nuclear structure, nuclear reactions, and nuclear astrophysics. Experiments will range from studies of light-ion nuclear reactions at very low rates carried out in inverse kinematics for the investigation of important issues in both nuclear structure and astrophysics, to measurements of multi-particle final states in complex heavy-ion reactions looking at the impact of changes in the N/Z ratio between target and projectile on the nuclear equation of state.

The AT-TPC will enable the necessary luminosities and resolution for reaction studies with relatively low beam intensities, significantly extending the science reach of the NSCL and FRIB. The design calls for a cylindrical TPC that will be housed in a superconducting solenoid, which will be operated at fields up to about 2 T. Valuable information on the operation of the AT-TPC will be obtained in the run-up to FRIB, which will guide whether improvements should be made for operation of the device with the higher beam rates that will become available.

With the implementation of the AT-TPC, it will be crucial to develop a better theoretical understanding of how the heavy-ion + heavy-ion data will improve our understanding of the nuclear equation of state. The EOS collaboration is encouraged to continue to work closely with theoretical groups in interpreting their data: the extraction of quantities like the symmetry energy can be challenging when one includes the full range of reaction-theory uncertainties.

F) HELIOS – like system

HELIOS is a high resolution spectrometer for low-energy light particle reaction products. The main physics motivation of HELIOS is the measurement of transfer and scattering reactions in inverse kinematics. The solenoid is designed in such a way that it enables the detection of light particles; i.e., p, d, t, and ^{3,4}He with excellent particle identification and with an energy dispersion directly translated from the center of mass. The power of the approach resides in the fact that the method does not suffer from the kinematic compression inherent to measurements carried out at fixed angles in the laboratory, such as those performed with Si arrays, and usually results in higher energy dispersion.

Owing to the existence of the HELIOS demonstrator, the anticipated capabilities of the new instrument are well established. A HELIOS-like device at FRIB is expected to be the instrument of choice for transfer reaction experiments with reaccelerated beams at 10^3/s or more to study single-particle strengths and particle correlations in exotic nuclei. It will also be important in areas such as indirect techniques for nuclear astrophysics and applications (such as stockpile stewardship, provided the applicability of the surrogate technique is demonstrated).

The experience with the demonstrator indicates that the technical issues have been resolved. The collaboration has nevertheless a number of important development efforts to consider. These include: the use of a magnet with a stronger field and/or a larger bore in order to bend the stiffest light particles (such as high-energy tritons); the use of γ-ray detection in combination with the spectrometer; the coupling of the device with a recoil spectrometer for an optimal detection of the beam-like reaction partner under certain conditions. Interactions with theorists to relate indirect techniques to direct reactions are encouraged.

With regard to the last two instruments, it should be noted that the AT-TPC would fit within the HELIOS magnet, especially if a large-bore solution is adopted. Hence, a dialog between the two collaborations is encouraged in order to explore this possibility, perhaps as a future upgrade path, provided the possibility to do this is incorporated in the initial design. The interest in collaborating also follows from a natural complementarity between the capabilities of HELIOS and the AT-TPC with the former measuring cross sections at beam intensities of 10^3/s and higher and the latter being limited to intensities of 10^4/s or smaller. In other words, for nuclei farthest away from stability where the beams are the weakest, measurements with the AT-TPC will be required, exploiting the instrument's efficiency at the expense of its energy resolution. For higher beam intensities that HELIOS can handle, the superb energy resolution of the device will be an asset.

G) Ion traps

The ion trap program at FRIB is expected to focus on high-precision mass measurements on short-lived rare isotopes and on selected fundamental symmetry measurements that might make use of special isotopes in which signals for new physics are enhanced. The program uses low-energy ion beams produced with the FRIB gas stopping system. It is envisioned that the future FRIB program will build on the current NSCL LEBIT facility, which became operational in 2004 and has been yielding high-precision mass measurements since 2005. Relative mass uncertainties for rare isotopes of $< 10^{-8}$ have been achieved. LEBIT includes a gas stopping cell and ion guide system, a cooler/buncher, and a 9.4 T Penning trap mass spectrometer. Near-term upgrades include the addition of a linear cryogenic gas stopper prior to 2012, and a cyclotron gas stopper after 2012. Other improvements will focus on more efficient removal of contaminants from the Penning trap, so that shorter lifetimes can be studied, and on the addition of a "mini trap" to allow continuous monitoring of the magnetic field, thus making future measurements more efficient and less subject to systematic uncertainties. Comparable facilities in North America also exist at Argonne (CPT) and TRIUMF (TITAN). The future FRIB program should benefit from technical advances based on this experience.

Precision mass measurements will be important to core areas of the FRIB program in structure and in nuclear astrophysics. In addition, there is the possibility of a significant contribution to fundamental symmetries. We encourage the ion-trap community to become more organized and active in looking for high-impact applications of the future FRIB ion trap program to fundamental symmetries. One possible direction is high-precision studies of β decay of the type being pursued at TRIUMF, to constrain new interactions such as a scalar contribution to the weak interaction.

The measurement of nuclear electric dipole moments is another possible program for FRIB, as the combination of ion traps and rare isotopes could open up new possibilities for finding nuclei with enhanced EDMs. We encourage the community to determine whether competitive opportunities exist in this area

H) Laser Spectroscopy / Neutral atom traps

Collinear Laser Spectroscopy with the BECOLA setup aims to obtain information on electromagnetic moments and charge radii of exotic nuclei. In the BECOLA scheme, radioactive ions from a gas stopping system are bunched via an ion trap system and transported to the laser ionization beam line. The ions are neutralized in a charge exchange cell. The neutral atoms are then delivered for laser spectroscopy. Neutral atoms could also be used for neutral atom trap experiments, such as parity non-conservation experiments in magneto-optical traps. Several techniques are necessary to achieve a reasonable accuracy. For instance, the stability of the high voltage supplied at the charge exchange cell is crucial in collinear laser spectroscopy. Recent measurements have demonstrated the possibility to access exotic nuclei with low yields, the regime of most importance for a program at FRIB. This experimental program needs an accumulation of techniques and experience. Thus, to start this program at the pre-FRIB stage is encouraged. In considering the initial programs and physics cases, emerging issues might be to choose specific elements and to coordinate with other institutes where gas stopping systems are employed for such laser and trap experiments.

Some of the caveats concerning a future fundamental symmetries program, for example using atom traps, mentioned at the end of the previous section, are relevant here as well. The SAC is aware of the many developments in North America and the world and hopes that the experience gained with those will strengthen an FRIB program in this area.

I) Neutron Detectors

Neutron detection, usually in conjunction with other detector systems, is important for a wide range of structure, reactions, and astrophysics experiments at FRIB. There are three broad areas where neutron detectors are needed.

(1) Reactions with fast beams such as heavy ion collisions, or knockout, where fast neutrons are produced (10s-100s MeV). These reactions are important at FRIB in order to probe the properties of the rarest isotopes beyond the neutron drip line, and the nuclear matter EOS. LANA and MoNA/LISA cover this area. LANA is an existing liquid scintillator wall with γ-neutron discrimination capability. An upgrade to this older detector is being discussed. MoNA is a plastic scintillator wall with γ-neutron discrimination capability, by time of flight. The expansion project LISA is underway and prepares the detector system for the FRIB era where higher beam energies require longer flight paths.

(2) Inverse kinematics reactions, such as (d,n) or (p,n), that emit neutrons, or neutron evaporation processes, which produce neutrons in the ~100 keV to 10 MeV range. These reactions are needed to probe the structure of rare isotopes, for indirect determinations of critical astrophysical reaction rates in the rp-process, and for charge exchange measurements to probe weak interaction strengths in isotopes of importance for nuclear structure and astrophysics. LENDA at NSCL and VANDLE at ORNL cover this area. They can be combined at FRIB. Both use plastic scintillator bars with low neutron detection thresholds around 100-200 keV for energy measurements via time of flight. LENDA is completed, while VANDLE is in the prototype stage and is expected to be completed in 2012. A third project is DESCANT at TRIUMF. It uses liquid deuterated scintillators for neutron-γ discrimination, and neutron energy measurements via time of flight and pulse shape. DESCANT is movable and could be available at FRIB.

(3) Beta-delayed neutrons with low energies ranging from one keV to a few MeV. Studying these processes will provide critical information for r-process studies and probe the structure of some of the most exotic isotopes within reach at FRIB. Neutron detection is the method of choice for very exotic nuclei where it is difficult to use γ spectroscopy for determining total

neutron emission branchings. The detectors listed in (2) could also be used in this research since they allow for neutron energy measurements and therefore enable β-delayed neutron spectroscopy. They can also be readily combined with γ detectors. However, they miss neutrons below ~100 keV making the determination of absolute branchings more difficult. In addition, to reach the most neutron rich nuclei requires detectors with the highest possible efficiencies. Both NERO at NSCL and 3Hen at ORNL are long, efficient neutron counters for energies from sub-keV to a few MeV. However, they provide only very crude neutron energy measurements and are therefore complementary to the scintillator-based detectors mentioned above. NERO exists and 3Hen is expected to be commissioned in 2010-2011.

From the discussion above, it is clear that an impressive suite of neutron detectors is available or in the very late stages of development. This collaboration should continue to assess whether these detectors take full advantage of FRIB capabilities. For high energy neutrons, new techniques to avoid cross talk should be considered. At medium energy, plastic-based detectors are straightforward solutions. At this initial stage of FRIB collaborations, consideration of the use of other scintillators might be worthwhile. For β-delayed neutron detection, future developments could focus on maintaining very high, constant, efficiency over a broader energy range. Those focusing on this area should also work to ensure compatibility with other classes of detection systems that will work in conjunction with neutron detectors.

J) Scintillators

Scintillators represent an important tool for the detection of γ radiation in many experiments with radioactive beams ranging from Coulomb excitation of intermediate-energy fragments, to the study of the γ decay of giant resonances, the measurement of short lifetimes by electronic methods in β decay or calorimetry in nuclear reactions, and astrophysical capture reactions. Generally, the use of scintillators will be preferred over the use of germanium technology in rather special circumstances such as when very weak exotic beams imply the use of detectors with the highest possible efficiency, or when sub-nanosecond timing is required. For these reasons, scintillator detectors are essential for the research program of FRIB.

Depending on the application, the required intrinsic capabilities of the scintillator of choice may vary. In some instances, energy resolution or time resolution may be more important than detection efficiency and/or size, for example. The wide variety of new scintillator materials that are being developed provide possible opportunities for use at FRIB and should be explored. At present, however, it is unclear which of the new materials that have recently appeared on the market, or which new technological ideas for scintillator materials, have the potential of developing into a practical and cost-effective tool for physics with radioactive beams. As the collaboration itself indicated, we encourage efforts to develop a coherent science case and a strategy for detector R&D needs to define detector systems that will optimize FRIB science. In addition, some existing and planned detection systems might be adequate for initial applications at FRIB.

K) Silicon Arrays

Silicon solid-state detectors have been widely used to study particle reactions in nuclear physics for over forty years. Their good energy resolution, linearity of response over a broad energy range, and ability to do particle identification have made them well suited to a large number of applications, such as elastic and inelastic scattering, transfer reactions, and reactions for nuclear astrophysics. Indeed, large area silicon detectors are now used routinely in multi-detector arrays to study nuclear reactions induced by very low intensity beams. Developments such as pixel by pixel readout have made silicon detectors also the choice for many charged-particle decay studies following implantation of radioactive nuclei and for decay tagging of reaction products in recoil spectrometers. There are issues, however, with the detectors available today that limit their applications, such as radiation damage that limits the lifetime of detectors and the often poor timing characteristics of large area detectors. R&D is needed on ways to improve the performance in both of these areas. Further R&D would be useful to determine how to make large area detectors that are substantially thicker than 1 mm.

Today, there is no substitute for silicon detectors for many applications. Thus, they likely will be critical for a wide range of experiments at FRIB. The community of experimentalists who depend on silicon detectors have recognized the importance of pushing the detector technology to make improvements in resolution, timing, radiation hardness, etc. They also continue to seek alternative detector materials. It is important that this community work together to continue pushing silicon technology and to seek other solutions in order to develop a coherent perspective on the use of these devices. We encourage the organization of workshops aimed at new detector technologies and upgrades to existing designs. Bringing together the broad community of users (including those outside of nuclear physics) and experts in materials may lead the way to new developments.

L) Decay Stations

Beta decay studies will be essential for the science mission of FRIB. They are a tool that can reveal properties of the most exotic isotopes within reach at FRIB, including many of the nuclei participating in the astrophysical r-process. In addition, decays can be used as an efficient tool to tag exotic isotopes, for example when performing in-beam γ-ray spectroscopy with reaccelerated beams at lower energies. An FRIB decay station will be a versatile system where different types of detectors can be combined and rearranged to meet the needs of specific experiments. The system has two major components: an implantation station, and a system of auxiliary detectors for the detection of decay products that leave the implantation area.

For implantation, two different types of active systems have been discussed: a highly segmented Si detector based system capable of dealing with high implantation rates, and a segmented Ge detector based system optimized for high detection efficiency at low implantation rates. A moving tape system would also be available. Required auxiliary detection systems include additional Si detectors for particle and β detection, highly efficient γ-ray detectors, and highly efficient neutron detectors. Gamma-ray detectors have to be optimized for high efficiency and only require moderate segmentation. While detectors used for other applications might be usable, the specific needs likely require specialized systems optimized for decay studies. Current projects include a proposed densely packed Ge system, and an existing total absorption spectrometer. A number of neutron detectors are available for decay studies as well (see Section II I). Careful coordination is required to ensure that current and planned auxiliary detectors can be used together in practical configurations.

The decay group should make an effort to develop a coherent strategy for decay experiments at FRIB and ensure close collaboration among all sub-groups. The decay group should include members of the γ-ray and neutron detection groups who are interested in decay experiments to ensure that all detector systems will be integrated effectively.

ISOTOPES AND APPLICATIONS

M) Isotopes and applications

Isotopes and applications of nuclear science are vital to the science and technology base of the US economy. The scientific discoveries and the associated potential advances made possible by applications of isotopes produced at FRIB span the scientific frontier widely from medicine, biology, physics, chemistry, to a broad range of challenges in environmental and material science. Isotope production and availability are crucial to various aspects of homeland security, detector development, drug discovery, health care therapies and diagnostics, and the development of new resources from petrochemicals to nuclear fuels.

FRIB will produce simultaneously hundreds of isotopes that can be harnessed for a variety of uses. Some expertise in nuclear chemistry and separation science will be crucial to harvest these isotopes. The conveners of the isotopes and application group suggested several areas for extracting isotopes of interest. This effort is important for the country and will require some special equipment (e.g., hot cells) and expertise. The group will seek R&D funds to develop ways of doing extractions for isotopes of interest. A specific question the collaboration should address is whether an on-site neutron generator would be useful to study critical neutron-induced reaction cross sections.

The SAC welcomes the planned Workshop of this working group in September on isotopes and applications to determine high-priority initiatives in this area, their feasibility, and the infrastructure requirements they entail. It would be important for the Workshop to address the equipment needs for this science.

INFRASTRUCTURE

N) DAQ

Without doubt, data acquisition and data storage will be major issues for FRIB. Already, detector systems in low-energy nuclear physics experiments are becoming more complex with many channels of readout. New developments such as ASICS, which make multi-channel readout systems relatively inexpensive, and full signal storage through flash ADCs, are adding enormously to the amount of data being collected. The increased beam intensities that FRIB will provide will tax the ability of DAQ systems to handle multi-GB/s data streams and will require huge data storage capability. An even larger problem looms as detector and instrument development takes place around the world.

In order for systems to work in concert, there must be standards adopted for implementing software readout of FRIB detectors and decisions made on control systems for FRIB equipment. The community must face this issue now in order to avoid a major problem in the future. One way to proceed would be to have the existing U.S. low-energy facilities and groups, in consultation with international groups that face similar issues, work together to ensure that DAQ systems and control systems evolve toward a common platform. International Workshops focused on this area would be beneficial. This effort should naturally lead to a well-defined protocol that all new detectors would need to follow for readout. With multiple types of detectors, it also will be critical to develop techniques such as time stamping to identify data from multiple detectors that belong to the same event. Fortunately, these issues are all tractable if groups begin to cooperate now.

O) Targets

Experiments at FRIB, and elsewhere, need a variety of targets. At FRIB, these include thin foils and films for reaccelerated rare beams, thick targets for fast beams, and gas targets. The unique capability at FRIB of reaccelerated rare beams requires a variety of targets involving thin foils for heavy-ion fusion reactions with proton-rich nuclei, and on the neutron-rich side for inverse direct reactions, β-decay studies, and Coulomb excitation, for example. In particular, proton, deuteron and tritium-loaded thin targets have to be prepared for direct reactions in inverse kinematics. Many of the experiments using these targets are of astrophysical importance. Furthermore, radioactive targets like Th, U, Pu, Cu, and Cf, and others obtained from harvesting will be needed for studies using the most neutron-rich FRIB beams. Several types of gas targets will be used at FRIB, including those that serve both as target and readout in the AT-TPC, and specialized gas jet targets for transfer reaction studies and for the measurement of capture reactions with the low-energy recoil separator for nuclear astrophysics.

In addition to their target making role, target laboratories are needed to prepare degraders, wedges, windows, and specialized calibration sources required for a variety of experimental devices. Other on-going activities concern the development of polarized targets, led by ORNL, and of cryogenic targets in collaborations between MSU and international partners. The availability of the needed target making capabilities, and a trained workforce, is a must for successful experiments at FRIB, and at other accelerators.

III Other items

Beam structure: Several of the detector system collaborations expressed concern about the intrinsic timing of the beams from the reaccelerator where beam pulses will be separated in time by only 12.5 ns. Such short pulsing prevents the effective use of timing with respect to the beam for most applications because of the well-known “wrap-around” problem in the time spectra where the detection of a reaction product can no longer be associated with a specific beam pulse. The committee encourages FRIB and NSCL management to address this issue with the working groups at the earliest possible time. Specifically, it is hoped that bunching of the beam with pulses separated by ~ 100 ns will be achievable without significant loss of intensity.

Floor space: Careful consideration of the layout of beam lines and instruments to accommodate the desired instruments within a finite floor space should be considered relatively soon.

Theory: While there was no explicit theory discussion at this instrumentation workshop, theory is essential for all areas of FRIB, and this was clear from many discussions in the working groups. An important consideration in the planning for FRIB will be strengthening of a supporting theory effort. Strengthening links with theory will also be critical for experimental efforts, especially those in the planning stage. For instance, in areas such as fundamental symmetry tests, theory plays a special role in helping experimentalists find opportunities for high-impact measurements. In the case of electric dipole moments, exotic nuclei may provide enhancements of signals for time-reversal-odd interactions. In areas such as EOS physics, a detailed theory is needed to determine whether measurements in heavy-ion collisions can isolate quantities of interest, like the symmetry energy, given parameter uncertainties in the reaction theory.

IV Conclusions

The palette of FRIB science is rich and impressive. The instruments discussed at this Workshop provide a compelling suite of techniques to attack the broadest range of physics opportunities. The SAC strongly supports these efforts. These projects were considered in the context of the 2007 NSAC Long Range Plan and the set of Experimental Campaigns outlined in the “Symons” NSAC report. We find that, taken as an ensemble, these existing and proposed projects cover all essential areas of the physics described in these documents: They will take the science of nuclei into a new era.

Above, we have provided assessments (not rankings) of each of these efforts. We stressed the synergistic links among many of the instruments, and between the instruments and the FRIB facility itself, and we encourage active, continuing dialog among all groups involved, including focused follow-up workshops where appropriate. We hope that this Report can provide guidance for the future development of FRIB and its instrumental infrastructure.

Appendix 1: The Charge Letter

MICHIGAN STATE
UNIVERSITY

December 30, 2009

Dear SAC Member:

The FRIB Users Executive Committee is organizing an FRIB equipment workshop from February 20 to 22 in East Lansing, Michigan at the East Lansing Marriott hotel. The purpose of the workshop is to collect information for the FRIB Conceptual Design Report that is due in July, 2010, on equipment plans of users. We will use the opportunity to provide feedback to FRIB equipment collaborations on the scientific relevance and priority of their initiatives. The workshop will begin at 13:00 on the 20th and finish by noon on the 22nd. In order to formulate the feedback, the SAC will meet at selected times during the workshop, in parallel to collaboration meetings, and in the afternoon following the workshop. We would also like to have a preliminary discussion during a working lunch from 11:30-13:00 on the 20th. We expect to be finished by 18:00 on the 22nd.

This letter describes your charge and role in the workshop. We would like you to attend the workshop and listen to as many of the sessions as possible. The workshop is organized around the activities of approximately 20 working groups. Details of the workshop can be found at http://meetings.nscl.msu.edu/frib-equipment-workshop2009/ . Prior to the workshop, the working groups will provide two-page summaries of the science to be addressed by the equipment they considered, status of existing equipment to meet the needs, proposed new equipment, the need for R&D, and facility requirements for the new initiatives proposed.

Based on the written information and what you hear at the workshop, we would like you to provide feedback to the FRIB Director and the user community in the form of a short (maximum 5 page) written summary of

- The status of equipment and equipment proposals to meet the goals of the scientific program presented in the 2007 NSAC LRP
- Completeness of the equipment needed to allow the 17 experimental campaigns of the RIB Task Force (see Table II of the Symons committee report) to be addressed; with major unfilled needs by current equipment flagged

FRIB

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University Distinguished
Professor and Director

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RARE ISOTOPE
BEAMS**

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- Comments on the importance and suitability of the equipment initiatives presented by the users at the workshop;
  - Importance should be rated by “highly important”, “important”, “importance not documented”, “insufficient information at this time”
  - Suitability should be rated by “optimal for the science program”, “suitable”, “insufficient information at this time”
- Comments on the relative priorities of the various equipment initiatives and identifications of potential duplicative developments

This report will be shared with the user community. In addition, you may want to include any other comments you have in a cover letter to the FRIB Director. This information will be shared with DOE, but not the user community.

We understand the significant burden this activity places on your time, but appreciate very much your contribution to making FRIB and the future experimental program a success. If you have any comments or questions regarding this charge, please contact Dr. Bradley Sherrill at 517-908-7718 (or Sherrill@frib.msu.edu). We look forward to seeing you at the meeting.

Sincerely,

Konrad

C. Konrad Gelbke

Appendix 2: SAC Members

Ani Aprahamian
University of Notre Dame

Richard Casten, Chair
Yale University

Wick Haxton
University of California, Berkeley
Lawrence Berkeley National Laboratory

Robert Janssens
Argonne National Laboratory

Karlheinz Langanke
GSI Helmholtzzentrum fuer Schwerionenforschung
Technical University Darmstadt
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Augusto Macchiavelli
Lawrence Berkeley National Laboratory

Witek Nazarewicz
University of Tennessee
Oak Ridge National Laboratory

Hiro Sakurai
RIKEN, Japan

Hendrik Schatz
Michigan State University

Robert Tribble
Texas A&M University

Kim Lister, Ex Officio
Argonne National Laboratory

Appendix 3: Glossary of acronyms used in this Report:

FRIB	Facility for Rare Isotope Beams
NSCL	National Superconducting Cyclotron Laboratory
SAC	Science Advisory Committee (to FRIB/NSCL)
DOE	Department of Energy
NSF	National Science Foundation
SECAR	Separator for Capture Reactions
JENSA	Jet Experiments in Nuclear Structure and Astrophysics
AT-TPC	Active Target & Time Projection Chamber
HRS	High Rigidity Spectrometer
S800	Existing NSCL High Resolution Spectrometer
GRETA	Gamma Ray Energy Tracking Array
GRETINA	Demonstrator for GRETA
HELIOS	Helical Orbit Spectrometer
DAQ	Data Acquisition System
ReA3	NSCL Re-accelerator for heavy ions to 3MeV/u for uranium
ReA12	NSCL Re-accelerator for heavy ions to 12MeV/u for uranium
DRAGON	Detector of Recoils and Gammas of Nuclear Reactions (ISAC)
ISAC	Isotope Separator and Accelerator (TRIUMF)
HRIBF	Holifield Radioactive Beam facility
ATLAS	Argonne Tandem Linac System
TRIUMF	Tri-University Meson Facility (Canada)
ADC	Analog to Digital Converter
ASIC	Application Specific Integrated Circuit
GB/s	Giga Byte /second
JINA	Joint Institute for Nuclear Astrophysics
SeGA	Segmented Gamma Array
CAESAR	Caesium Iodide Scintillator Array
LENDA	Low Energy Neutron Detector Array
MoNA-Lisa	Modular Neutron Array (plastic)
ISLA	Isochronous Spectrometer with Large Acceptance
RMS	Recoil Mass Spectromter (ORNL)
FMA	Fragment Mass Analyzer (ANL)
SUPERB	Separator for Unique Products of Expts. with Radioactive Beams
MRI	Major Research Instrument
EOS	Equation of State
LEBIT	Low Energy Beam Ion Transport System (NSCL)
TITAN	TRIUMF’s Ion Trap for Atomic and Nuclear Physics
CPT	Canadian Penning Trap

EDM	Electric Dipole Moment
BECOLA	Beam Cooler and Laser for At. & Nucl. Phys. Spectr. End station (NSCL)
LANA	Large Area Neutron Array (liquid scintillator)
VANDLE	Versatile Array of Neutron Detectors at Low Energy
DESCANT	Deuterated Scintillator Array for Neutron Tagging
3HEN	^{3}He Neutron Array (ORNL)
NERO	Neutron Emission Ratio Observer