NSCL and the Facility for Rare Isotope Beams (FRIB) Project

The National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU), shown in Figure 1, is the largest campus-based nuclear science facility in the United States. NSCL is funded by the National Science Foundation (NSF) for operating its Coupled Cyclotron Facility (CCF) as a national user facility and for conducting research in nuclear physics, nuclear astrophysics, and accelerator physics.

The Facility for Rare Isotope Beams (FRIB) will be a new U.S. Department of Energy Office of Science (DOE-SC) national user facility supporting the mission of the Office of Nuclear Physics. The FRIB Project designs and establishes FRIB. FRIB will make effective use of NSCL's infrastructure when it becomes operational. The FRIB Project is funded by the DOE-SC, MSU, and the State of Michigan. When FRIB construction is complete, NSCL will cease operations and merge into FRIB, and FRIB operations will be funded by the DOE-SC. The NSCL user group has already merged into the FRIB User Organization (FRIBUO) that has over 1,250 members and approximately 20 working groups.

NSCL and the FRIB project have over 500 employees, including more than 35 faculty members with joint appointments in MSU's Departments of Physics and Astronomy, Chemistry, and Electrical and Computer Engineering. Presently, more than 140 students—approximately half of them doctoral students—are employed and educated at the laboratory.

NSCL maintains and operates two coupled superconducting cyclotrons, a high-acceptance superconducting fragment separator, a superconducting linear reaccelerator, and a diverse set of experimental apparatus. The CCF is capable of delivering a broad range of primary beams from hydrogen to uranium that are used for the in-flight production of secondary, rare isotope beams with energies up to nearly 170 MeV/nucleon. The in-flight technique allows for sub-microsecond isotope separation in a chemistry-independent way with short beam development times of a few hours to one day. The high beam energies provide efficient access to nuclei very close to the drip-lines, both because thick targets can be used and because ions in mixed beams ("cocktail beams") can be identified on an event-by-event basis. Rare isotopes produced with the in-flight technique can be stopped in and extracted from a He gas cell and subsequently used for precision ion trap or laser spectroscopy experiments at very low energy or for charge breeding and reacceleration with a state of the art superconducting linac dubbed ReAx where x denotes the maximum energy per nucleon of uranium ions that can be delivered by a particular linac section. A first experiment with reaccelerated beams from ReA1.5 has been conducted in August 2013. Beams from ReA3 will be available for research in late 2014 and an upgrade to ReA6 is in the advanced design stage and may come on-line in 2015–2016 depending on funding.

Figure 1. *NSCL building complex on the campus of Michigan State University.*

The current layout of NSCL's experimental areas is shown in Figure 2. Major experimental apparatus includes the large-acceptance high-resolution S800 Spectrograph and the high-field Sweeper Magnet, the high-resolution array HiRA for charged-particle detection, high-resolution and high-efficiency γ-ray detection systems (the Segmented Germanium Array SeGA and the Caesium Iodide Array CAESAR, respectively), neutron detection arrays suited for various energies (Modular Neutron Array—MoNA and its extension LISA, Neutron Emission Ration Observer—NERO, Low-Energy Neutron Detector Array—LENDA and the Neutron Walls), the Beta Counting System (BCS) as well as beta NMR/NQR setups, diamond timing detectors, the low-energy beam and ion (Penning) trap facility LEBIT, and the

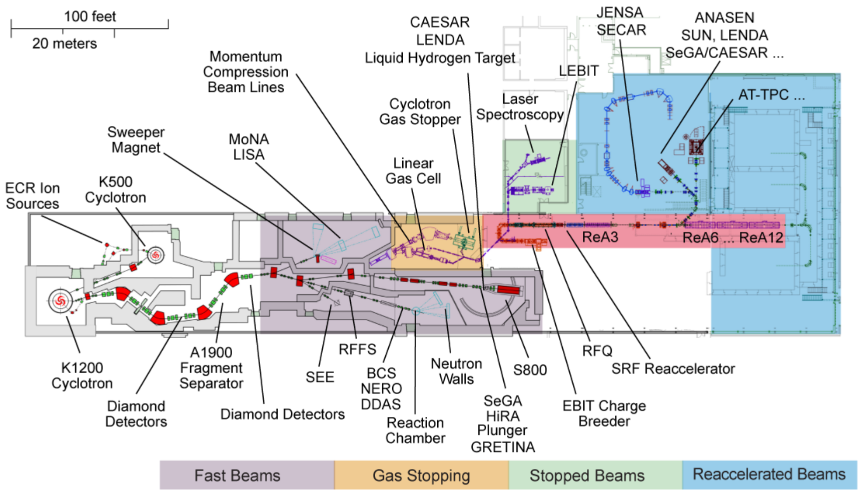

Figure 2. *Schematic layout of the NSCL facility. The experimental area utilizing reaccelerated beams from ReA6 is schematic with the final layout driven by user demand (see text for the status of equipment).*

beam-cooler and laser spectroscopy facility BECOLA. A superconducting linear re-accelerator (ReA3) and its dedicated experimental area, beam-lines, and apparatus are nearing completion. For research with reaccelerated beams, an active-target time projection chamber (AT-TPC), a multi-purpose beam-line, a gas-jet target and a SEparator for CApture Reactions (SECAR) are currently under construction or in the advanced planning stages. In the past year, NSCL hosted the advanced γ-ray tracking array GRETINA. After successful completion of an extended scientific campaign, GRETINA was moved to the ATLAS facility at ANL in the summer of 2013. The first experiment with reaccelerated rare isotopes in the new ReA3 experimental hall at NSCL was performed in August 2013 with the Array for Nuclear Astrophysics Studies with Exotic Nuclei (ANASEN) built by Florida State University and Louisiana State University.

Research at NSCL addresses important questions in basic nuclear physics, nuclear astrophysics, accelerator physics, and associated instrumentation research and development. About 5−10% of the beam time is allocated to cross-disciplinary and applied research. Beam time is approved by the NSCL director who is advised by a Program Advisory Committee (PAC) consisting of several internationally accomplished experts from other institutions.

DOE-SC and MSU signed the Cooperative Agreement to design and establish FRIB on 8 June 2009 (Figure 3). In September 2010, the project received Critical Decision 1 approval from the DOE-SC acquisition executive. In August 2013, DOE-SC approved a performance baseline of $730 M with an associated completion date in 2022 (Critical Decision 2). The Project is managed to an early completion in December 2020. Also approved was Critical Decision 3a, which allows the project to proceed with long-lead procurements. Commencement of the start of civil construction is subject to a Fiscal Year 2014 appropriation.

FRIB will provide researchers opportunities to study the properties of rare isotopes and to put this knowledge to use in various applications, including in materials science, nuclear medicine, and nuclear weapons stockpile stewardship. The research areas include:

- Nuclear Structure—What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes? What are the limits of nuclear existence?
- Nuclear Astrophysics—What is the nature of neutron stars and dense nuclear matter? What is the

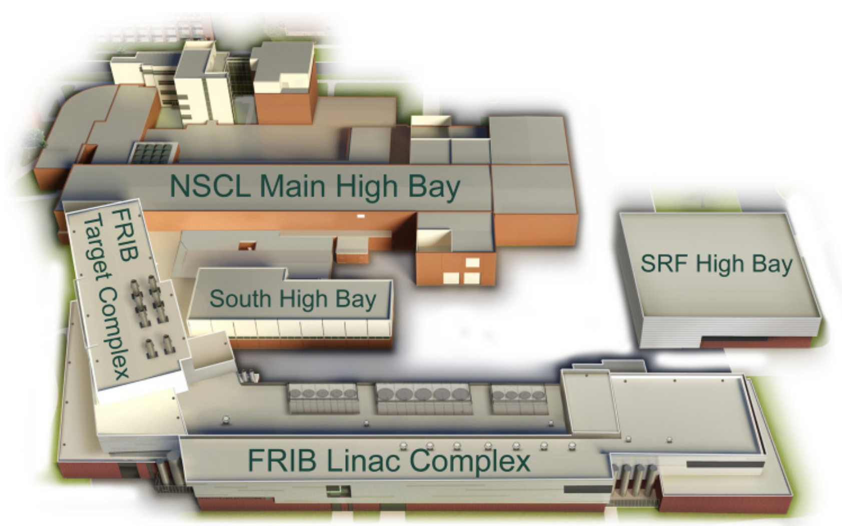

Figure 3. *Architect's rendering of the baselined Facility for Rare Isotope Beams (FRIB).*

origin of elements heavier than iron in the Cosmos? What are the nuclear reactions that drive stars and stellar explosions?
- Tests of Fundamental Symmetries—Why is there now more matter than antimatter in the Universe?
- Application of Isotopes to Society—What are the potential uses in medicine, energy, material sciences, and national security?

The FRIB design provides for fast, stopped, and reaccelerated beams of rare isotopes. Features of the FRIB design include:

- A state-of-the-art superconducting-RF driver linear accelerator provides 400 kW for all beams with uranium accelerated to 200 MeV/nucleon and lighter ions to higher energies (protons up to 600 MeV).
- Space in the linac tunnel and shielding in the production area allows upgrading the driver linac energy to 400 MeV/nucleon for uranium and 1 GeV for protons without significant interruption of the future science program.
- A high-power in-flight production target and a three-stage high-acceptance, high-resolution fragment separator produce and deliver rare isotopes with high rates and high purity.
- Provisions have been made in the fragment separator to allow future implementation of isotope harvesting and the addition of (limited) multi-user capability.
- Space is available and provisions have been made in the facility design to allow the addition of a second target facility, for example for ISOL beam production with protons or light ions up to 400 kW.
- Three beam stopping stations—two gas stopping stations and one solid stopper—will provide "stopped" beams with highest efficiency for precision experiments and for reacceleration.
- A superconducting-RF reaccelerator will be able to provide beams up to 12 MeV/nucleon (uranium) and higher energies for lighter beams (e.g., 21 MeV/nucleon for ^{48}Cr).
- Large experimental areas (47,000 sq. ft.) can accommodate new experimental apparatus for science with stopped beams, reaccelerated beams, and fast beams. The site as space available to double the size of experimental areas or for housing additional rare-isotope research facilities.
- A full set of well-tested experimental equipment is already in place for research in all FRIB science areas.
- Opportunity for a pre-FRIB science program using the existing in-flight separated beams from the Coupled Cyclotron Facility and the ReA3 reaccelerator. Users will be able to mount and test equipment and techniques and do science with beams at all energies in-situ so that they are immediately ready for experiments when FRIB is complete; this will allow for a continually evolving science program during the time FRIB is under construction, which will seamlessly merge into the research program at FRIB.
- A User Relations Office supports ongoing research with the CCF and the development of new user programs and experimental equipment.

The final design of the FRIB conventional facilities—the tunnel and support buildings—is complete. Preconstruction site preparation is complete and pilings for the earth-retention system have been placed. Research and development activities have been successfully completed, with much of the R&D work accomplished in collaboration with national laboratories. Final design of the technical systems—accelerator and experimental equipment—is underway and anticipated to be substantially complete in 2014.

For more information on the FRIB Project, see http://www.frib.msu.edu. The independent FRIB Users Organization website is http://www.fribusers.org.

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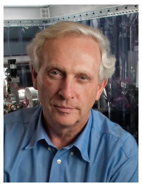

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