Facility for Rare Isotope Beams Overview

Bradley Sherrill
Director NSCL, FRIB Scientific Director
Outline

- Introduction – This workshop is a wonderful opportunity to discuss mutual goals, challenges, and collaboration
- Overview of FRIB
- Challenges
- Capabilities
- Experimental equipment
- Science program - harvesting
Funded by the US DOE– Office of Science Nuclear Physics Program with contributions from Michigan State University

Key feature is 400 kW beam power for all ions ($8 \mu A$ or $5 \times 10^{13} ^{238}U/s$)

Separation of isotopes in-flight provides
- Fast development time for any isotope
- Beams of all elements and short half-lives
- Fast, stopped, and reaccelerated beams
FRIB Civil Construction Substantially Complete – Now Installing Accelerator

FRIB construction site March 2017  
Web cameras at www.frib.msu.edu
FRIB Timeline

- Early 1990s – Community effort to push construction of a new rare isotope facility (ISOL)
- 2002 NSAC Long Range Plan endorsement
- 2007 NSAC Top priority for new construction
- September 2010 – CD-1 approved
- April 2012 – Lehman review, baseline and start of civil construction
- August 2013 – CD-2 approved (baseline), CD-3a approved (start civil construction pending FY2014 federal appropriation)
- March 2014 – Start civil construction
- August 2014 – CD-3b approved (technical construction)
- October 2017 – First accelerated beam in LINAC hall
- by December 2017 – Planned first liquid from FRIB cryoplant
- 2021 – End of NSCL operations
- 2021 – Early completion goal
- June 2022 – CD-4 (scheduled project completion)
FRIB Partners

- Argonne National Laboratory
  - Liquid lithium charge stripper; Stopping of ions in gas; Fragment separator design; Beam dynamics; SRF

- Brookhaven National Laboratory
  - Radiation resistant magnets; Plasma charge stripper

- Fermilab
  - Diagnostics

- Jefferson Laboratory
  - Cryogenics; SRF

- Lawrence Berkeley National Laboratory
  - ECR ion source; Beam dynamics

- Oak Ridge National Laboratory
  - Target facility; Beam Dump R&D; Cryogenic Controls

- Stanford National Accelerator Lab
  - Cryogenics

- Sandia
  - Production target

- Budker Inst. of Nuclear Physics (Russia)
  - Production target

- GANIL (France)
  - Production target

- GSI (Germany)
  - Production target

- IMP of CAS (China)
  - Magnets

- INFN Legnaro (Italy)
  - SRF

- KEK (Japan)
  - SRF technology, SC solenoid magnets

- RIKEN (Japan)
  - Charge strippers

- Soreq (Israel)
  - Production target

- Tsinghua University (China)
  - RFQ

- TRIUMF (Canada)
  - SRF, beam dynamics
FRIB Accelerator Building

J. Wei (head of FRIB Accelerator Division), P. Ostroumov, J. Yamazaki, K. Saito, et al.
Accelerate ion species up to $^{238}\text{U}$ with energies of at least 200 MeV/u

Provide beam power up to 400kW

Energy upgrade to 400 MeV/u for $^{238}\text{U}$ by filling vacant slots with 12 SRF cryomodules

Provisions for ISOL upgrade
FRIB Accelerator Performance

200 MeV/u Beam energy
400 kW Beam power

FRIB Beam Energy (MeV/u)

Ion

P  He  D  C  O  Ar  Ca  Zn  Kr  Xe  Bi  U
Cryomodule Production, Testing, and Installation Underway

Chemical processing of cavities

Coldmass assembly in clean room

Cryomodule assembly (four of five bays)

The three $\beta=0.041$ cryomodules installed and being cabled up in the FRIB tunnel
FRIB Cryoplant Overview
Scheduled to Make 4K Liquid in 2017, 50% larger than SNS Cryogenic Plant

- Warm compressor installed
- 4 K cold box installed
- Cryogenic control room
- Transfer lines to tunnel and distribution in tunnel installed
- Cryogenic control room
Beam Power

\[ P[kW] = I[\mu A] \times E[GeV/u] \times A \]

- FRIB operation will be challenging like facilities such as SNS or JPARC
- FRIB will have multiple different beams
- FRIB may change beams every couple weeks

Y. Yamazaki

**Challenge of FRIB – High Power Accelerators**
36Ar and 86Kr will be developed as part of FRIB Project, primary beams beyond 36Ar and 86Kr will be developed during early operations and operations.

Additional beams will be added each year, power increased over 5 years.

Proposal is to run 32 weeks/y for science, but will take time to reach that due to complexity of accelerating multiple charge states.

Beam losses will limit power ramp-up, mitigation takes time and experience.

Past experience for proton machines, SNS and J-PARC, indicates steep learning curve.

<table>
<thead>
<tr>
<th>Year 1 Beams</th>
<th>Notional Weeks Year 1</th>
<th>Years after CD-4</th>
<th>Beam power on target goal (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>238U</td>
<td>6</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>48Ca</td>
<td>3</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>78Kr</td>
<td>2</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>82Se</td>
<td>3</td>
<td>4</td>
<td>200</td>
</tr>
<tr>
<td>124Xe</td>
<td>1</td>
<td>5</td>
<td>400</td>
</tr>
<tr>
<td>18O</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>86Kr</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16O</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36Ar</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FRIB Facility Overview

Experiments with fast, stopped and reaccelerated beams

Reaccelerator

Ion source

400 kW superconducting RF linear accelerator

Rare isotope production area and isotope harvesting

FRIB Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

B. Sherrill 2nd China-US-RIB Meeting, Slide 14
In-Flight Production of Rare Isotopes at NSCL

Example: $^{86}\text{Kr} \rightarrow ^{78}\text{Ni}$

$^{86}\text{Kr}^{14+}$, 12 MeV/u

$^{86}\text{Kr}^{34+}$, 140 MeV/u

The same concept will be used at FRIB, but with a new LINAC and separator.

Three stage fragment separator for production and delivery of rare isotope beams (high power preseparator and high resolution stage 2 and 3)

Must be able to accommodate 400 kW and allow ion-by-ion ID
Vessels for Rare Isotope Production
Fabricated, Installed and Leak Checked

April 5, 2017 - 5:00 am

April 5, 2017 - 8:00 am
Rotating Carbon Production Target

F. Pellemeoine et al. (W. Mittig)

- Multi-slice rotating graphite disk target
  - Capable of withstanding 400 kW primary beam
  - 30 cm diameter disks rotating at 5000 rpm
  - High power density: ~ 20 - 60 MW/cm³

- Target module on track for on-schedule completion
  - 99% of target module parts ordered - 65% received

- Additional early operations target will be developed
  - “Ladder” with multiple targets, blank, and viewer screen to be exchanged with rotating target disk module
Beam Dump Status: Rotating Drum with Water

F. Pellemeoine et al. (W. Mittig)

- Thin-walled water-filled rotating drum
  - Water cools drum shell and absorbs up to 325 kW of beam power

- Additional static beam dump for commissioning and first years of operation to be developed

- Working on harvesting of isotopes from the water – White Paper in preparation (G. Severin et al.)
FRIB Estimated Beam Rates

https://groups.nscl.msu.edu/frib/rates/fribrates.html

O. Tarasov, et al.
EPAX 2.15

Note: Possibility to collect unused isotopes for target material for \((n,\gamma)\) studies
Users are organized as part of the independent FRIB Users Organization (FRIBUO)
- Chartered organization with an elected executive committee
- Approximately 1,400 members (250 Institutions world wide, 51 countries) as of September 2017
- 19 working groups on instruments

Yearly User Meeting

Science Advisory Committee Advice on User Initiatives
- 2011 Review of equipment initiatives
- 2012 Review of FRIB design
- 2013 Review of equipment working group progress
- 2015 Review of equipment priorities
- 2016 Reviewed day-1 science program and major equipment status
- Next SAC meeting 2018 (Equipment)
- First PAC about one year prior to operation
FRIBB Facility Overview

Experiments with fast, stopped and reaccelerated beams

Reaccelerator

Ion source

400 kW superconducting RF linear accelerator

Rare isotope production area and isotope harvesting
Current Facility – National Superconducting Cyclotron Laboratory (NSCL)

- National User Facility funded by US National Science Foundation – NSCL 85 graduate and 120 undergraduate students
- NSCL enables forefront research: Stability of atomic nuclei, history of element formation, search for new physics, applications of isotopes for societal needs
- Opportunity to prepare for FRIB: Same user group FRIBUO, 1400 members (50 nations involved)
- First system for in-flight separation and reacceleration of rare isotopes ReA3, which became operational in 2015

Operation of NSCL user facility is supported by NSF Physics Division
ReA3 (soon ReA6) at NSCL

Details:
• 2015: ReA3 Operational (8 rare isotope experiments completed)
• 2017: Approval from NSF for ReA6 (pending)
• ReA3 experimental area has three beam lines
Helium-Jet Ion-Guide System (HJ-IGS) for commensal (multi-user) operation at NSCL

- Rare isotopes that would otherwise be lost are caught in a high-pressure cell filled with a helium-aerosol mixture placed off-axis in the fragment separator.
- Collected isotopes are transported through a capillary to the helium-jet ion source, where helium is pumped away and the rare isotopes are ionized.
- Rare isotopes can be used in the stopped and reaccelerated experimental areas.
FRIB Experimental Capabilities
Radioactive Ion Beams are needed/available in three energy domains

**Fast** 50-200 MeV/u

**Stopped**

**Reaccelerated** (NSF support) → 0.3 to 10 MeV/u (eventually to 20 MeV/u)
<table>
<thead>
<tr>
<th>Item</th>
<th>Status</th>
<th>Item</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRETINA</td>
<td>Operational</td>
<td>Penning Traps</td>
<td>Operational</td>
</tr>
<tr>
<td>GRETA</td>
<td>CD1 2017</td>
<td>Scintillator Arrays</td>
<td>Conceptual stage</td>
</tr>
<tr>
<td>SECAR</td>
<td>Completed 2020</td>
<td>Silicon Arrays</td>
<td>Operational and Conceptual</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>stage</td>
</tr>
<tr>
<td>Recoil Separator</td>
<td>White paper in 2014</td>
<td>SiEFUS</td>
<td>NSF MRI</td>
</tr>
<tr>
<td>ReA12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Rigidity</td>
<td>Preliminary design and</td>
<td>Atom Traps</td>
<td>Under development at ANL/</td>
</tr>
<tr>
<td>Spectrograph</td>
<td>white paper 2014</td>
<td></td>
<td>TRIUMF</td>
</tr>
<tr>
<td>SOLARIS</td>
<td>DOE ANL, Planning</td>
<td>Harvesting</td>
<td>White Paper 2017</td>
</tr>
<tr>
<td>MONA/LISA</td>
<td>Operational</td>
<td>AT-TPC</td>
<td>Operation in 2015</td>
</tr>
<tr>
<td>Decay Station</td>
<td>Existing Equipment;</td>
<td>ANASEN</td>
<td>Operational</td>
</tr>
<tr>
<td></td>
<td>White paper 2017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BECOLA</td>
<td>Operational</td>
<td>SUN</td>
<td>Operational</td>
</tr>
<tr>
<td>CRIS</td>
<td>NSF MRI</td>
<td>CAESER</td>
<td>Operational</td>
</tr>
<tr>
<td>VANDLE/LENSDA</td>
<td>Operational</td>
<td>ReA3 (3-6 MeV/u)</td>
<td>Operation in 2015</td>
</tr>
<tr>
<td>EOS Detector</td>
<td>TPC at RIKEN; conceptual</td>
<td>ReA6 (6-10 MeV/u)</td>
<td>NSF Approved 2017</td>
</tr>
</tbody>
</table>
Future Equipment Opportunities

- Fundamental symmetries traps
- Storage Rings
- TPC for EOS studies
- Active target for high energy

Blue/Green NSCL
Red FRIB
Light Green - Expansion
FRIB Scientific Program

Structure

Nuclear Astrophysics

Applications

Fundamental Symmetries
Application of FRIB Isotopes

- FRIB offers fast development for thousands of isotopes (via harvesting in parallel to normal operation)
- Isotopes extracted from the water of the beam dump or in catchers located along the fragment separator (offering parallel operation)
- Isotopes for medical research
  - Examples: $^{47}$Sc, $^{62}$Zn, $^{64}$Cu, $^{67}$Cu, $^{68}$Ge, $^{149}$Tb, $^{153}$Gd, $^{168}$Ho, $^{177}$Lu, $^{188}$Re, $^{211}$At, $^{212}$Bi, $^{213}$Bi, $^{223}$Ra (DOE Isotope Workshop)
  - $\alpha$-emitters $^{149}$Tb, $^{211}$At: potential treatment of metastatic cancer
  - Cancer therapy of hypoxic tumors based on $^{67}$Cu treatment/$^{64}$Cu dosimetry
- Tracers for Marine Studies ($^{32}$Si), Condensed Matter ($^{8}$Li), industrial tracers ($^{7}$Be, $^{210}$Pb, $^{137}$Cs, etc.), ...
- Data for advanced reactor design and destruction of nuclear waste
Summary

- FRIB construction is going well and is scheduled to be completed by 2022 (Early completion in 2021)
- Key features of FRIB include 400 kW primary beams, fast-stopped-reaccelerated beams of rare isotopes
- Described FRIB LINAC, cryoplant, target, beam dump, separator, experimental areas and equipment
- FRIB will enable a broad science program: Structure, Nuclear Astrophysics, Fundamental Symmetries, and Applications of Isotopes