How to produce a radioactive beam?
with an emphasis on FRIB

slides excerpted from a talk titled

The Context of the School

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presented at the 6th Summer School on Exotic Beam Physics (August 2007)

the entire presentation, as well as rest of the talks at the school, is available here:
http://www.orau.org/ria/ria07/program.htm
History of RIA/FRIB project

- 1996 NSAC Long Range Plan recommendation for in-flight facility (NSCL CCF) and a reaccelerated beam facility when RHIC construction is substantially complete.
- 1999 NSAC ISOL Task Force:
  - **RIA concept** - The scientific potential of the RIA facility will be maximized by integrating multiple techniques for producing and separating then accelerating and utilizing these isotopes.
  - **The RIA design should accommodate fast in-flight separated beams.**
- 2002 NSAC Long Range Plan:
  - **RIA is the highest priority for major new construction… but requires funding beyond DOE budget.**
- 2003 DOE 20-year Facilities Plan:
  - **RIA is tied for third.**
- Extensive RIA R&D efforts involving all major US laboratories have resolved the technical issues.
- Detailed facility plans developed at ANL and MSU, received wide support from the user community.

- 2005: National Academies Committee (Rare Isotope Science Assessment Committee — RISAC) asked (by NSF & DOE) to evaluate Rare Isotope Science in the international context (GSI/FAIR and RIKEN/RIBF).

- February 2006: Secretary Bodman states DOE support for the construction of a U.S. exotic beam facility for about half the cost of RIA with unique capabilities.

- March 2006: Argonne & MSU present plans to RISAC satisfying the goal of a world-class facility at about half the price of RIA.

- July 2006: Nuclear Science Advisory Committee (NSAC) asked to: 1. evaluate technical concepts for such a facility and 2. to update Long Range Plan for Nuclear Science.

- Dec 2006: RISAC gives such a facility, the Facility for Rare Isotope Beams (FRIB) strong endorsement.
Significant Events in the Evolution of the Nation’s Plans for FRIB

- Dec 2006: Argonne and MSU present technical concepts to NSAC for Facility for Radioactive Ion Beams.

- March 2007: Ray Orbach states that a facility for rare isotope beams is in the plan DOE is presenting to Congress for its future facilities.


Recommendations for the 2007 NSAC Long Range Plan

- We recommend completion of the 12 GeV Upgrade at Jefferson Lab. The Upgrade will enable new insights into the structure of the nucleon, the transition between the hadronic and quark/gluon descriptions of nuclei, and the nature of confinement.

- We recommend construction of the Facility for Rare Isotope Beams, FRIB, a world-leading facility for the study of nuclear structure, reactions and astrophysics. Experiments with the new isotopes produced at FRIB will lead to a comprehensive description of nuclei, elucidate the origin of the elements in the cosmos, provide an understanding of matter in the crust of neutron stars, and establish the scientific foundation for innovative applications of nuclear science to society.

- We recommend a targeted program of experiments to investigate neutrino properties and fundamental symmetries. These experiments aim to discover the nature of the neutrino, yet unseen violations of time-reversal symmetry, and other key ingredients of the new standard model of fundamental interactions. Construction of a Deep Underground Science and Engineering Laboratory is vital to US leadership in core aspects of this initiative.

- The experiments at the Relativistic Heavy Ion Collider have discovered a new state of matter at extreme temperature and density—a quark-gluon plasma that exhibits unexpected, almost perfect liquid dynamical behavior. We recommend implementation of the RHIC II luminosity upgrade, together with detector improvements, to determine the properties of this new state of matter.
Complement the major investments in Europe and Japan in fast-beam fragmentation facilities by focusing on unique **reaccelerated exotic beams**. The facility will provide the full capabilities of stopped, reaccelerated and in-flight beams.

- **200 MeV/u** superconducting linac driver will provide higher yields of all isotopes.

- With reaccelerated beams based on gas-stopping and ISOL, FRIB vastly exceeds the capabilities of all reaccelerated beam facilities.

- FRIB will provide the higher reaccelerated beam energies needed for some of the science (single-particle structure and pairing).

- FRIB can be built for about ½ the cost of RIA (~$550 M) by capitalizing on existing strengths and facilities.
How do you make exotic beams?

Current Techniques

- Projectile Fragmentation
  - Heavy ion accelerator
  - Thin production target
  - Fragment separator
  - Radioactive ion beam

- ISOL
  - Production accelerator
  - Thick, hot target
  - Isotope / isobar separator
  - Postaccelerator

A Better Way

- Projectile Fragmentation Based ISOL
  - Heavy ion accelerator
  - Thin production target
  - Fragment separator
  - Gas cell stopper / Ion guide
  - Postaccelerator

Specific to FRIB

- Fast Gas Catcher to combine advantages of fragmentation and stopped beams.
- Superconducting driver linac and post-accelerator for all ions from hydrogen to uranium.
- Acceleration of ions in multiple charge states to increase performance.
- Realizable designs for high power (>100 kW) targets.
- Efficient reacceleration of \(1^+\) charge states.
Each of the four beam energy ranges is required for important physics

< 12-15 MeV/u
- Framework of single-particle states and closed shells
- Interplay of deformation and single particle effects
- Physics at the proton drip line
- Heavy elements
- Fission barriers
- Indirect measurements of astrophysical processes

< 1.5 MeV/u
- Direct measurements of reactions in hot stars. rp-process and breakout of hot CNO cycle

Non-accelerated
- Fundamental symmetries.
- PV, EDM, Beta-decay studies of physics beyond the standard model
- Masses - r-process, rp-process, symmetries
- Nuclear moments by hyperfine interactions
- Beta decay studies of rare nuclei

APPLICATIONS

In-Flight
- Limits of stability at drip lines
- Decay studies at the limits of stability
- Matrix elements connecting to ground state. E&M and breakup
- Halos and skins
- Indirect measurements of astrophysical processes
- Nuclear equation of state

Experimental Areas:
1: < 12 MeV/u  2: < 1.5 MeV/u  3: Nonaccelerated  4: In-flight fragments
Concrete designs for FRIB exist

- all agree on core capabilities: stopped, reaccelerated and fast beams
- all agree on driver concept, beam power, beam energy

AEBL @ ANL

ISF @ MSU


http://www.nscl.msu.edu/future/isf/
Energy bunching/fast gas catcher concept

This technology enables reaccelerated beams of a large class of elements not possible with standard ISOL technology.
200 MeV/u 400 kW $1^+$ yields

FRIB
200 MeV/u 400 kW
Yields of mass separated $1^+$ ions for re-acceleration
T-gas cell: 20 ms
The gas catcher concept is essential to the global competitiveness of FRIB

Tested at ATLAS

Tested at GSI
From 2007 to FRIB: 
ATLAS: Californium Rare Isotope Breeder Upgrade - CARIBU

- 1 Ci $^{252}$Cf fission source + gas catcher provide $1^+/2^+$ ions
- Cf fission fragments are shifted to heavier masses and are generally more refractory than those from U – unique beams at unique energies
- Low-q ions fed into ECR source, modified to be a ‘charge breeder’
- Yields from source up to $10^7$ /s
- On-target max ~ $5 \times 10^5$ /s
- Technology and experience important for AEBL/FRIB
- First beams: 2008 non-accelerated, 2009 accelerated

Uranium fission
From 2007 to FRIB
HRIBF with IRIS2
From 2007 to FRIB
NSCL: Gas Stopping, Charge Breeding & Post Acceleration

And let’s not forget new developments at University-based facilities:
RESOLUT (FSU), TAMU RIB
As well as continued development of instrumentation
GRETINA, HELIOS,...
Summary

- New exotic beam capabilities are coming on-line in the coming years at the DOE Users facilities (CARIBU at ATLAS, High-power target at HRIBF, Post-accelerator at NSCL).

- FRIB is on the horizon (NSAC Recommendation, Strong DOE support).

- A 400 kW 200 MeV/u based facility offers unique physics reach in isotopes and reaccelerated beam energy.

- It complements the world-wide efforts in rare isotope physics, in particular the fast beam projects at GSI and RIKEN.

- It is better than any ISOL facility for the many isotopes that do not diffuse easily from a thick target.

- It can be built for about half the cost of RIA.

- It offers natural upgrade paths as we explore the physics of this new regime of unknown nuclei.