Status of the Rare Isotope ReAccelerator Facility ReA

D. Leitner
on behalf of the ReA team at
Michigan State University
Outline

• Introduction
• ReAcclerator facility
• Commissioning Results and Status
• First radioactive ion beam delivery
FRIB Accelerator Complex Subsystems

ReAccelerator Facility

- Fast Beam Area
- Gas Stopping
- Stopped Beam Area
- Reaccelerator
- Fragment Separator
- Production Target Systems
- Beam Delivery System
- Linac Segment 1
- Linac Segment 2
- Linac Segment 3
- Folding Segment 1
- Folding Segment 2
- Front End

J. Wei, NA-PAC'13 FRYBA1, Slide 3
Isotope production reaction mechanisms [1]

Most post accelerator facilities are based on

**ISOL – Isotope Separator On-Line (target “spallation” or fission)**
- Light ion-induced “spallation” or fission of heavy targets
- Isotopes must diffuse from hot targets and effuse to an ion source
- Typical beams ~100-1000 MeV protons; typical targets Ta & UC
- Photofission using high power electron linac

- Very intense beams of many elements, especially noble gases and alkalis
- Weak beams of refractory and chemically active elements

Several facilities around the world:
Rex-Isolde, Spiral, ISAC, EXYPT, SPES, EURISOL …
Isotope production reaction mechanisms [2]

• **In-flight heavy-ion fragmentation or fission on a light target**
  – Fragments of the beam are kinematically forward directed at ~beam velocity
  – Rare isotopes are separated physically; no chemical dependence
  – Typical heavy ion beams are $^{18}\text{O}$- $^{238}\text{U}$ at 200-2000 MeV/u; typical targets Be or C

• Separated beams of any species including refractory and chemically active elements and isotopes with very short half-lives, even isomers

• Needs gas catcher or solid stopper for post acceleration

ReA at MSU is the first post-accelerator coupled to a fragmentation facility
CCF Is The Only Facility In The World That Provides Fast, Stopped, And Reaccelerated Beams Of Rare Isotopes
In-flight Fragmentation Offers A Wide Variety Of Rare Isotopes

At the Coupled Cyclotron Facility at MSU (≈10 years of operations) more than 1000 RIBs have been produced and more than 870 RIBs have been used in experiments with > 90% availability.

Average experiment: primary beam 120 hrs, several secondary RIB beam changes
ReA SC Post-Accelerator – 3 stages  
(41 SC SRF cavities)

Requirements: Variable energies 300keV/u – 12MeV/u

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionization efficiency for all elements</td>
<td>&gt; 20 %</td>
<td>EBIT charge breeder + high efficiency linac</td>
</tr>
<tr>
<td>Beam rate capabilities</td>
<td>$10^8$ ions/sec</td>
<td>Hybrid EBIS/T charge breeder</td>
</tr>
<tr>
<td>High beam purity</td>
<td></td>
<td>A1900, EBIT CB, Q/A</td>
</tr>
<tr>
<td>Low energy spread, short pulse length</td>
<td>1keV/u, 1nsec</td>
<td>Multiharmonic external buncher and tight phase control in SRF linac</td>
</tr>
</tbody>
</table>
Rare Isotope Beam Production

$^{40}$Ca primary beam
At 140 MeV/u

Production rate $\sim 1.3 \times 10^5$ PPS/pnA,
Purity for K-37 $\sim 50%$
$dp/p = 0.5%$

D. Leitner NA-PAC 2013, slide 9
Rare Isotope Beam Thermalization: RIB Beams Gets Further Purified

ANL 1.2 m long linear gas cell
High purity helium: ~ 90 Torr, -5°C
Thermalizes RIB ions to < 1eV
Singly and doubly charged

Variable degrader and wedge for further purifying the beam

Fast RIBs (100 MeV/u) From CCF

Second gas catcher or cyclotron stopper

Electrostatic Transport Line at 60keV

Analyzing Magnet

94% $^{37}\text{K}^+$

MOPMA07, J.A. Rodriguez et al, “The D-Line Project at MSU”

D. Leitner NA-PAC 2013, slide 10
Rare Isotope Beam Thermalization Station

Commissioned 2012/2013
ReA Design Choices: EBIT Charge Breeder

EBIT:
- Short breeding time
- High ionization efficiency
- Charge state flexibility
- Low beam contamination
- $0.5 \geq \frac{Q}{A} \geq 0.2$
Charge Breeding In The EBIT Source

Electron beam

Magnetic field

Electron collector

Trap electrodes

Highly charged ions

Continuously injection and accumulation (~100 ms)

A^+

Pulsed extraction (100 µs to ms)

A^{Q+}

Radial electron-beam space-charge potential

Axial potential well from the trap electrodes

Over-the-potential barrier injection

Lower-the-barrier extraction

D. Leitner NA-PAC 2013, slide 13
EBIT Background Spectrum And Selection Of $^{37}\text{K}$ Charge States

![Diagram showing analyzed current vs mass/charge ratio](image)

D. Leitner NA-PAC 2013, slide 14
Background ion intensities from the charge breeder in the region of interest are less than 1 pA.
ReA Design Choices: RT-RFQ With External Buncher And High Efficiency SC-Linac

**SRF LINAC**
- 80.5 MHz RF frequency
- Flexible energy range (deceleration 300keV/u to maximum linac energy in small steps)
- External multi harmonic buncher to minimize the longitudinal emittance

Pilot source

- EBIT
- MHB

RT RFQ

Q/A

n+ RIB beam

1+ RIB beam

0.041 modules

0.035 module FY14

D. Leitner NA-PAC 2013, slide 16
Room Temperature Radio Frequency Quadrupole (RFQ)

- Pulsed operation (160kW, 25%)
- Energy Boost: 12 keV/u - 600 keV/u
- 4-rod structure, 92 cells, 3.3 m long
- Buncher: 80.5MHz, 161MHz, (241.5 MHz)
- Nom 82% beam capture measured

Q. Zhao et al., PAC’07; D. Leitner et al, PAC’11; W. Wittmer et al., NA-PAC’13 (MOPSM07)
Compact Superconducting Linac With 2 Types Of Quarter Wave Resonators

- 7 β=0.041 cavities are in operation since 2010 with excellent performance and stability
- Routinely operated at 160% of the specified gradient

### Measured Phase and Amplitude Stability

<table>
<thead>
<tr>
<th>Cavity</th>
<th>Phase Std dev (deg)</th>
<th>Amplitude Std dev (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>82</td>
<td>0.149</td>
<td>0.025 %</td>
</tr>
<tr>
<td>84</td>
<td>0.207</td>
<td>0.009 %</td>
</tr>
<tr>
<td>85</td>
<td>0.043</td>
<td>0.018 %</td>
</tr>
<tr>
<td>88</td>
<td>0.14</td>
<td>0.013 %</td>
</tr>
<tr>
<td>89</td>
<td>0.06</td>
<td>0.020 %</td>
</tr>
<tr>
<td>91</td>
<td>0.248</td>
<td>0.046 %</td>
</tr>
</tbody>
</table>

D. Leitner et al., SRF'2011

D. Leitner NA-PAC 2013, slide 18
Compact Superconducting Linac With 2 Types Of Quarter Wave Resonators

- Cryomodule 3 will be installed and commissioned in 2014
- $\beta=0.085$ cavities were redesigned to reliably provide high gradient acceleration fields

- Eleven $\beta=0.085$ cavities have been tested (all tested well above specifications)
- CM4 (FRIB prototype) 2015, novel bottom up design

FRYBA1, J. Wei et al, “Progress towards the Facility for Rare Isotope Beams”
A. Facco et al., IPAC’2012

D. Leitner NA-PAC 2013, slide 19
ReA linac has a lot beam diagnostics to support the wide range of beam intensities.

### Diagnostic Systems Are Very Challenging For RIB Post-accelerators
(Dynamic Range 10 pps To 10^{12} pps)

<table>
<thead>
<tr>
<th></th>
<th>Diagnostics</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>FC</td>
</tr>
<tr>
<td>2</td>
<td>Slit profile monitor</td>
</tr>
<tr>
<td>3</td>
<td>Viewer, MCP or crystals</td>
</tr>
<tr>
<td>4</td>
<td>Bunch lengths, timing</td>
</tr>
<tr>
<td>5</td>
<td>Slits, aperture</td>
</tr>
<tr>
<td>6</td>
<td>Attenuators</td>
</tr>
<tr>
<td>7</td>
<td>Detectors (decay, scattering, in beam)</td>
</tr>
<tr>
<td>8</td>
<td>MCP, TOF</td>
</tr>
<tr>
<td>9</td>
<td>Pepperpot</td>
</tr>
<tr>
<td>10</td>
<td>Emittance Scanner</td>
</tr>
<tr>
<td>11</td>
<td>Energy defining slits</td>
</tr>
<tr>
<td>12</td>
<td>BPM</td>
</tr>
</tbody>
</table>

D. Leitner NA-PAC 2013, slide 20
ReA Beam Line Is Well Understood
Design compares well with the actual tuning parameters of the beam line

Beam Envelope

Linac transmission RIB beams ≈ 70%

MOPSM07, W. Wittmer et al.
The ReA Linac (CM1+CM2) Was Characterized Using Stable Beams

- Absolute energy calibration of ReA using 992 keV Al(p,γ) resonance
- Linac was tuned in 2 keV energy steps
- Measured energy spread of 0.5% FWHM is close to predicted value

CAESAR Detector Array

L. Ling-Ying et al., manuscript under preparation

D. Leitner NA-PAC 2013, slide 22
For Rare Isotope Beam Operations Pilot Beams Are Used To Pre-tune The Linac

MOPSM07, W. Wittmer et al.
For Rare Isotope Beam Operations Pilot Beams Are Used To Pre-tune The Linac

D-Line N4 Stopped beams A1900

Background Ion from EBIT

Counts

Energy [MeV]

241Am calibration source

40Ar^{13+}

MOPSM07, W. Wittmer et al.
For Rare Isotope Beam Operations Pilot Beams Are Used To Pre-tune The Linac

Am calibration source

Charge Bred Beam
$^{87}\text{Rb}^{28+}$
from the EBIT

MOPSM07, W. Wittmer et al.
For Rare Isotope Beam Operations Pilot Beams Are Used To Pre-tune The Linac

EBIT CB
RFQ
CM1
CM2
CM3 (2014)

D-Line
N4 Stopped beams
A1900

Low Energy
Experimental hall

SECAR

First RIB beam delivered

AT-TPC

MOPSM07, W. Wittmer et al.

- $^{15}\text{N}^7$, A/Q=2.1428
For Rare Isotope Beam Operations Pilot Beams Are Used To Pre-tune The Linac

EBIT CB
RFQ
CM1
CM2
CM3 (2014)

D-Line
N4 Stopped beams
A1900

Low Energy
Experimental hall

First RIB beam delivered

SECAR

AT-TPC

MOPSM07, W. Wittmer et al.
Radioactive Ion Beam Measured In The ANASEN Ionization Chamber

Contaminant beams in same setting as $^{37}$K$^{17+}$

Reaccelerated $^{37}$K RIB

First radioactive ion beam delivery to user 8/20/2013!
Summary

• ReA is the first post-accelerator coupled to a fragmentation facility

• The EBIT charge breeder provides high purity beams

• The SC cavities perform above specification and have been operated reliably since 2010

• Commissioning and final installations are progressing well, RIB beams below or close to the Coulomb barrier (light ions) will available for users in 2014

• The first radioactive ion beam was delivered to users in August of 2013

• ReA will serve as post accelerator for FRIB
Co-authors

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