The Advanced Rare Isotope Laboratory
ARIEL
June 18, 2014

Isotopes for Science and Medicine

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TRIUMF Accelerators:

- **500 MeV, 350 µA, H⁻ cyclotron**
- **4 medical isotopes cyclotrons** (TR13, CP42, TR30x2)
- **ISAC 50kW ISOL facility**
  - RFQ, $3 \leq A/q < 30$
  - DTL, $A/q \leq 7$, 0.1-1.8 MeV/u
  - 40 MV Heavy Ion SC linac
- **ARIEL e-linac (10mA, 50 MeV)**
Targets:
SiC, TiC, NiO, Nb, ZrC, Ta, UC

Ion sources:
- Surface
- Resonant Laser
- FEBIAD

Yield Chart of Nuclides

N=Z program
Nova X-ray burster
shell evolution
halo program

J. Lassen et al.
P. Kunz et al.

Ion Guide-LIS

J. Lassen et al.

ISAC isotopes
Isotopes for developing a standard model for nuclear physics:
• probing ab-initio theory in light and medium-mass nuclei
• understanding the role of 3N forces in the shell evolution of nuclei

Isotopes as laboratories search for new forces in nature:
• Setting world-leading limits on physics beyond the standard model
• Developing leading EDM experiments for the atom (RnEDM) and electron (FrEDM)

Isotopes to determine the origin of the heavy elements in the universe:
• Understanding the nucleosynthesis in nova and x-ray bursters
• Delineating the r-process path and identifying its astrophysical origin

Isotopes as probes of magnetism at interfaces and surfaces:
• Expanded user program in depth controlled $\beta$-NMR
• Understand magnetic and electronic properties of surfaces and interfaces
• Develop better battery materials

Isotopes for molecular imaging of diseases and treatment of cancer:
• Produce research quantities of alpha emitting isotopes for targeted alpha tumor therapy
• Develop new designer isotopes for diagnostics and treatment
ISAC Experimental facilities and programs

- TITAN Penning Trap facility
- EMMA recoil mass analyzer
- TIGRESS in-beam gamma-ray spectrometer
- Nuclear Structure
- Nuclear Astrophysics
- Fundam. Symmetries
- Materials Science
- Laser polarizer line
- Francium trapping facility
- TRINAT magneto optical trap
- MTV Mott scattering drift chamber
- IRIS solid hydrogen reaction set-up
- DESCANT
- GRIFFIN
- DRAGON recoil separator
- TUDA reaction setup
ARIEL will be TRIUMF’s flagship Rare Isotope Beam facility for the production of isotopes for science and medicine. ARIEL uses proton-induced spallation and electron-driven photo-fission of ISOL targets for the production of short-lived, rare isotopes that are delivered to multiple experiments simultaneously at the ISAC facility.
Advanced Rare IsotopE Laboratory

Existing

ISAC

Low Energy

Medium Energy

High Energy

Cyclotron

Existing

Kruecken - ARIEL - CAP 2014
Advanced Rare IsotopE Laboratory

Existing ARIEL I (CFI + BCKDF)

ARIEL II (CFI proposal by 19 universities)

Cyclotron

ISAC

Low Energy

Medium Energy

High Energy

June 18, 2014

Kruecken - ARIEL - CAP 2014
Completing & operating ARIEL absolutely central to realizing laboratory vision:

**Global leadership for Canada in Isotopes for Science & Medicine**

Substantially expands capabilities:
- Three simultaneous beams
- More and new isotopes
- Enables new experiments
- Expands national & international users
- International partnership w/ India
- World-leading capabilities
- Serves Canada and society

Implementation:
- Two new drivers: electron & proton
- Two new target stations and front end
- Interleave science with construction
ARIEL: Synergies & Connections

Isotopes for Science and Medicine
Nuclear Physics
Nuclear Medicine
Materials Science

Accelerator Technology
Particle Physics

Graduate Research
Accelerator Physics
ARIEL Buildings Occupancy

- Culmination of 3 years work
- Meets needs of entire ARIEL scope

*Association of Consulting Engineering Companies of BC.

ACEC-BC* Award of Merit, 2014
April 11

June 18, 2014
e-linac: MW-class Superconducting Electron Accelerator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Kinetic energy (MeV)</td>
<td>50</td>
</tr>
<tr>
<td>Average current (mA)</td>
<td>10</td>
</tr>
<tr>
<td>Duty Factor</td>
<td>100%</td>
</tr>
<tr>
<td>Beam Power (MW)</td>
<td>0.5</td>
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Photo-fission products using 50 MeV 10 mA electrons onto Hg convertor & UC<sub>x</sub> target.

100 kW, 25 MeV electrons by 2014

500 kW, 50 MeV electrons by ~2020
300 kV electron gun

- 10 mA thermionic gridded gun, emittance 5 μm rms
- RF modulated grid at 650 MHz
- Use of dielectric waveguide to transmit modulation from ground potential to gun
- Gun commissioning June 2013
Multi-cell SRF cavity fabrication by PAVAC, Inc.

Status:
- Three cavities delivered
- One more in fabrication
Cold test start 2014/04/17

2014/04/07 Cold mass in cryostat

2014/04/25 2K cold test complete.
• E-gun and injector cryomodule installed in e-hall
• Commissioning started (CNSC license for 3kW, 10mA egun, 4K cooldown of ICM)
• On track for fall delivery of 25MeV, 100kW beam
**ARIEL e-Linac: Installation & Commissioning Status**

- Electron source operated at 300 kV, up to 10 mA peak current @ 1% duty factor
- Klystron integrated RF system test has been completed at 1kW level
- RF delivered to cavity on resonance at 4K
  - Cavity RF field sustained in self-excited loop in accelerating mode
- Next steps: lock the field in amplitude and phase, at 4 or 2K – increase gradient to 10MV/m
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Phase 1: Li-8 for $\beta$-NMR

Goals:

- Photo-production of Li-8 in a Be-9 target using bremsstrahlung photons produced by stopping 100 kW electron beam in a solid metal target, and delivered to $\beta$-NMR.

Requires:

- ARIEL e-linac 30 MeV 100 kW
- Non-actinide target station with solid converter
- Pre-separator & beamline to $\beta$-NMR
Phase 1 will be done in collaboration with VECC - Kolkata:

- In August 2013 MoU Add-3 was signed
- Scope includes two ARIEL target modules, tested in ARIEL, and front-end beamlines
Phase 2: Photo-fission for r-process studies

Goals:
- Production and delivery of neutron-rich fission fragments by implementing actinide targets in conjunction with the solid photo-converter.

Requires:
- east target station w/ actinides
- hotcell for work w/ actinides
- Medium Resolution Separator

Milestones:
First photofission beams from the e-linac to ISAC
Phase 3: Purified accelerated high mass RIBs

Goals:
- Transport ISAC RIBs with A>29 to the ARIEL building for advanced purification & charge breeding and deliver them to the ISAC energy experimental areas.
- A collection station for medical isotopes will be implemented.

CFI-funded CANREB project provides the essential components required for the ARIEL front-end: EBIS, HRS, RFQ cooler.

Requires (within ARIEL II):
- 60 m LEBT beamlines
Phase 4: Actinide Production for Fundamental Symmetry Tests

Goals:
- Implement new proton beamline (BL4N) from cyclotron, delivering up to 100 $\mu$A at 500 MeV of proton beam to the West Target Station.

Requires:
- Proton beamline BL4N
Phase 5: Full power e-linac to reach most exotic neutron rich nuclei

Goals:
- Increase the energy and power of the e-linac beam to full design specification 50 MeV, 500kW, producing up to $10^{14}$ fissions per second.

Requires:
- additional Accelerator Crymodule w/ 2 cavities
- additional klystron
Science Drivers
1. Increased beam time to $\beta$-NMR for full user program
2. Pure, heavy mass accelerated RIBs (from ISAC & ARIEL)
3. Reaching the r-process using photo-fission (w/ highest beam energy)
4. Enable long beam times for Fundamental Symmetries & Nuclear Astrophysics
5. Isotopes for Nuclear Medicine R&D

Technical and other Objectives
- Delivery of three simultaneous RIBs to users
- High intensity photo-converter development (to enable 500 kW operation)
- Extend TRIUMF’s core competencies in SRF and high power targets

Phased Implementation
- Phased construction enables continuous stream of scientific results from ARIEL.
ARIEL-II: Completion to Science

$32.4M CFI application

19 participating universities (w/ envelope)
June 2010
ARIEL Project begins

August 2013
ARIEL Building complete

January 2013
CANREB CFI funding announcement

August 2013
TRIUMF-VECC MOU Add-3 signed

April 2013
ARIEL-II Phase 1

September, 2014
e-linac Phase 1
Complete

ARIEL-II Phase 2

April 2014
ARIEL-II Phase 2

March 2015
ARIEL-II CFI decision

ARIEL-II Phase 3

May 2015
ARIEL-II Phase 3

Fundamental Symmetries
Two ARIEL beams

ARIEL-II Phase 4

February 2016
ARIEL-II Phase 4

(Bl4N)
Fundamental Symmetries
Two ARIEL beams

ARIEL-II Phase 5

March 2016
ARIEL-II Phase 5

Extend r-process reach

January 2017
ARIEL-II CFI funding
announcement

September, 2017
ARIEL-II Phase 5

Fundamental Symmetries
Two ARIEL beams

June 2018
ARIEL-II Phase 5

Extend r-process reach
Unified theory for all nuclei
- halo / dripline nuclei & ab-initio theory
  ➔ high power proton beam
- shell evolution and 3N forces
  ➔ high power electron beam

Origin of the heavy elements
- H & He burning
  ➔ High power proton beam
  ➔ Beam development time
  ➔ Long beam times
- r-process in neutron-rich nuclei
  ➔ High power electron beam

Fundamental Symmetries
- Francium and Radon EDMs and PNC
  ➔ High power proton beam
  ➔ Long beam times

➔ Need high-power proton and electron production in full multi-user operation w/ 3 production targets
Thank you!

Merci!
High Power Commissioning, beam power up to 100 kW.

Accelerator Commissioning, beam energy up to 30 MeV

- Part 4: beam average power progressively increased from 100 W up to 30 kW
- Part 3: EACA second SRF cavity installed & commissioned; beam accelerated up to 30 MeV at the EHD dump. Beam power limited to 100 W.

- Part 2: EHAT and EHDT beamlines and EHD dump are added, and commissioned to 1 kW beam power.
- Part 1: EACA cryomodule (with a single SRF cavity), EABT and EABD are added; EACA equipment commissioned; beam accelerated to 20 MeV at EABD dump.

Injector Commissioning, beam energy up to 10 MeV

- Part 3: beam average power progressively increased to 1 kW at EMBD dump
- Part 2: EINJ cryomodule, EMBT to EMBD are added; EINJ equipment commissioned; beam power < 100 W, 10 MeV.
- Part 1: GUN, ELBT and ELBD commissioned to 300 keV

Red denotes CFI subset
Projection ARIEL: FLUKA, using the converter-target geometry and experimental diffusion times, and extraction and ionization efficiencies from ISOLDE, overlaid with the isotope specific half-live. Uncertainty in projection: factor \~ 10. (TRIUMF 5YP page 422), SPIRAL: GANIL web site.
Photo-fission on UC$_x$-target