THE N=126 FACTORY: A NEW FACILITY TO PRODUCE VERY-HEAVY NEUTRON-RICH ISOTOPES

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ATLAS/CARIBU FACILITY

- Stable beams at **high intensity** and energy up to 10-20 MeV/u
- Light in-flight radioactive beams
  - *light beams, no chemical limitations, close to stability, acceptable beam properties*
- **CARIBU beams**
  - *heavy n-rich from Cf fission, no chemical limitations, low intensity, ATLAS beam quality, energies up to 15 MeV/u*
- State-of-the-art instrumentation for Coulomb barrier and low-energy experiments
- Operating 5000-6000 hrs/yr (+ 2000 hrs/yr CARIBU stand alone) at about 95% efficiency
  - Common PAC for ATLAS and CARIBU
  - 350 users per year performing experiments at ATLAS

Access to n-rich region via fission of the most neutron-rich "available" very heavy nuclei (i.e. $^{252}\text{Cf}$)
NEW TOYS AT ATLAS SINCE LAST EMIS CONFERENCE

AGFA gas-filled spectrometer

AIRIS in-flight separator

EBIS charge-state breeder

new CARIBU low-energy area
Experiments this month with reaccelerated CARIBU beams using EBIS: Coulomb excitation of $^{104,106}\text{Mo}$, $^{110}\text{Ru}$, $^{100}\text{Zr}$.

CARIBU + EBIS charge breeder + GRETINA + CHICO2

EBIS vs ECR Beam Quality: $^{106}\text{Mo}$ (408 MeV) + $^{208}\text{Pb}$

Now vs Last EMIS
Experiments this month with reaccelerated CARIBU beams using EBIS: Coulomb excitation of $^{104,106}$Mo, $^{110}$Ru, $^{100}$Zr

Switched yesterday to $^{110}$Ru … first 11 hours of beam, similar high beam purity
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R-PROCESS STUDIES AT ATLAS

Current program:
• Masses and decay for r-process (N=82 and rare-earth peak)

Next 5 years program:
• Masses and decay for r-process last abundance peak (N=126 peak region) and extension of work above CARIBU and at the heaviest nuclei

ACCESSING ISOTOPES OF INTEREST FOR THE LAST R-PROCESS ABUNDANCE PEAK: THE N=126 FACTORY

Makes these critical nuclei available as a good quality mass separated low-energy beam.
AN EXAMPLE OF HOW TO DEAL WITH SPACE-CHARGE: CARIBU “FRONT END” LAYOUT

Main components of CARIBU

- **PRODUCTION**: “ion source” is $^{252}$Cf source inside gas catcher
  - Thermalizes fission fragments
  - Extracts all species quickly
  - Forms low emittance beam

- **SELECTION**: Isobar separator and MR-TOF
  - Purifies beam

- **DELIVERY**: beamlines and preparation
  - Switchyard
  - Low-energy buncher and beamlines
  - Charge breeder to Increase charge state for post-acceleration
  - Post-accelerator ATLAS and weak-beam diagnostics
ACCESSING ISOTOPES OF INTEREST FOR THE LAST R-PROCESS ABUNDANCE PEAK: THE N=126 FACTORY

N=126 factory design is a simplified CARIBU for MNT reactions

- CW operation of “pre-separation” stage dealing with high intensity
- Pulse operation of high-resolution separation stage
The N=126 factory

136Xe beam from ATLAS

198Pt target

198Pt target

To experiments (CPT, decay station, etc.)

Gas catcher (ANL) - under construction

Cooler/buncher (ANL/ND) - under construction

MR-TOF (ND) - commissioning

The N=126 factory
THE N=126 FACTORY: HIGH-INTENSITY GAS CATCHER SYSTEM

arator
(R ≈ 1000)

Cooler-Buncher

To CPT
THE N=126 FACTORY: ISOBAR SEPARATOR
THE N=126 FACTORY: RFQ BUNCHER
THE N=126 FACTORY: MRTOF SYSTEM BEING COMMISSIONED AT NOTRE-DAME
CROSS-SECTION FOR MULTI-NUCLEON TRANSFER VERSUS FRAGMENTATION

Hirayama et al., EPJ Web Conferences 109, 08001 (2016)

$^{136}$Xe $+ ^{198}$Pt at 10 MeV/u (best multi-nucleon transfer (MNT) reaction)

$^{208}$Pb $+ ^{9}$Be at 1 GeV/u (fragmentation reaction with best cross-sections for $N = 126$)
EXPECTED REACH OF $N = 126$ FACTORY… AROUND $N = 126$

Isotopes available, mass separated, at $> 1/s$ for mass measurements or decay studies.
What can the N=126 factory do near the rare earth fission peak?

Major extension over what is possible now in this region ... can map the possible kink at N=104.
### Measurements on Very Heavy Nuclei

**136Xe + 251Cf (50 mCi)**

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**238U + 248Cm**

for very n-rich Z~100
NEXT BIG STEP AT ATLAS: MULTI-USER UPGRADE

- EBIS beams represents 1-3% duty factor
- Combine pulsed EBIS beam with stable ECR beam
  - Address high demand on facility
  - Enable long duration experiments
  - Maximize efficient accelerator usage

ECR stable beam, ~95 ms
EBIS pulse, ~1 ms @ 10Hz

Combine beams: 4-15 MeV/u
Separate beams: 4-7 MeV/u
ATLAS MUU OPENS UP TOTALLY NEW POSSIBILITIES FOR R-PROCESS STUDIES

- Use stable beam 95% of duty cycle to produce N=126 isotopes
- Feed back N=126 isotopes into EBIS and reaccelerate in 1-3% of duty cycle
- Provides Coulomb energy beams of N=126 nuclei to address fissionability of nuclei in this region … critical to understand fission recycling in r-process

ECR stable beam, ~95 ms
EBIS pulse, ~1 ms @ 10Hz

Combine beams
Separate beams

4-15 MeV/u $^{136}$Xe
4-7 MeV/u $^{220}$Pb, …
What region can it cover for the r-process?

+ longer term, insight into fissionability of heaviest neutron-rich nuclei
CONCLUSIONS / STATUS

- More nuclear physics inputs needed to better understand the astrophysical r-process
  - Large ongoing project at ATLAS/CARIBU on N=82 and rare-earth peak regions
  - Next step is the N=126 abundance peak

- Atomic masses are the most important nuclear data input for r-process abundance calculations … they can be measured with very low yield.

- The N = 126 beam factory aim to produce nuclei of importance for the r-process that are difficult of access: N = 126 shell, above fission peaks, and actinides.

- Beam factory gas catcher, isobar separator, cooler-buncher and MRTOF are under assembly.

- The N=126 factory can do a lot more than N=126 nuclei.

Collaboration

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