TRIUMF

Canada's National Laboratory for
Particle and Nuclear Physics

ARIEL at TRIUMF: science, status and opportunities

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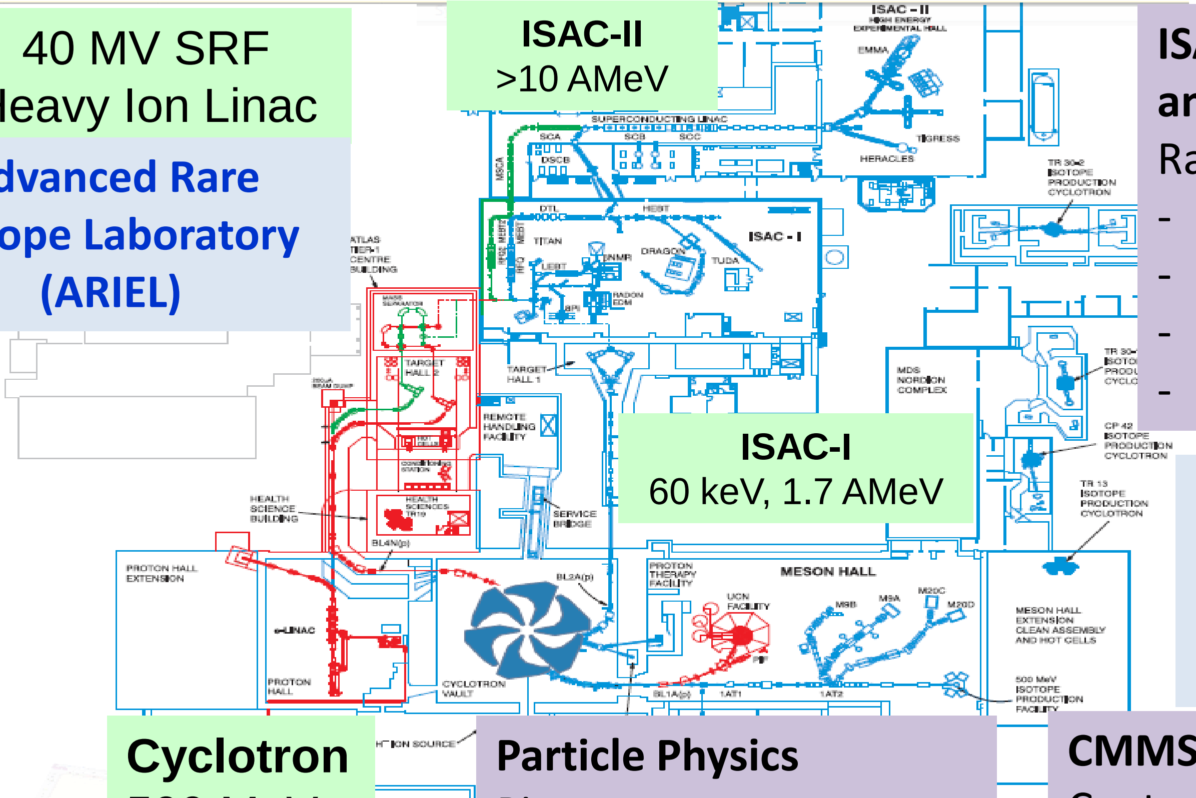
Adelaide Convention Centre, Australia
11-16 September 2016

TRIUMF: Canada's National Laboratory

TRIUMF was founded in 1968 and has delivered nearly 50 years of accelerator-based science and innovation for Canada, and is engaging the World.

TRIUMF's accelerator complex



40 MV SRF
Heavy Ion Linac

Advanced Rare Isotope Laboratory (ARIEL)

ISAC-II
>10 AMeV

ISAC-I
60 keV, 1.7 AMeV

ISAC (Isotope Separator and ACcelerator)
Rare Isotope Facility
- Nuclear Structure
- Nuclear Astrophysics
- Fund. Symmetries
- CMMS (βNMR)

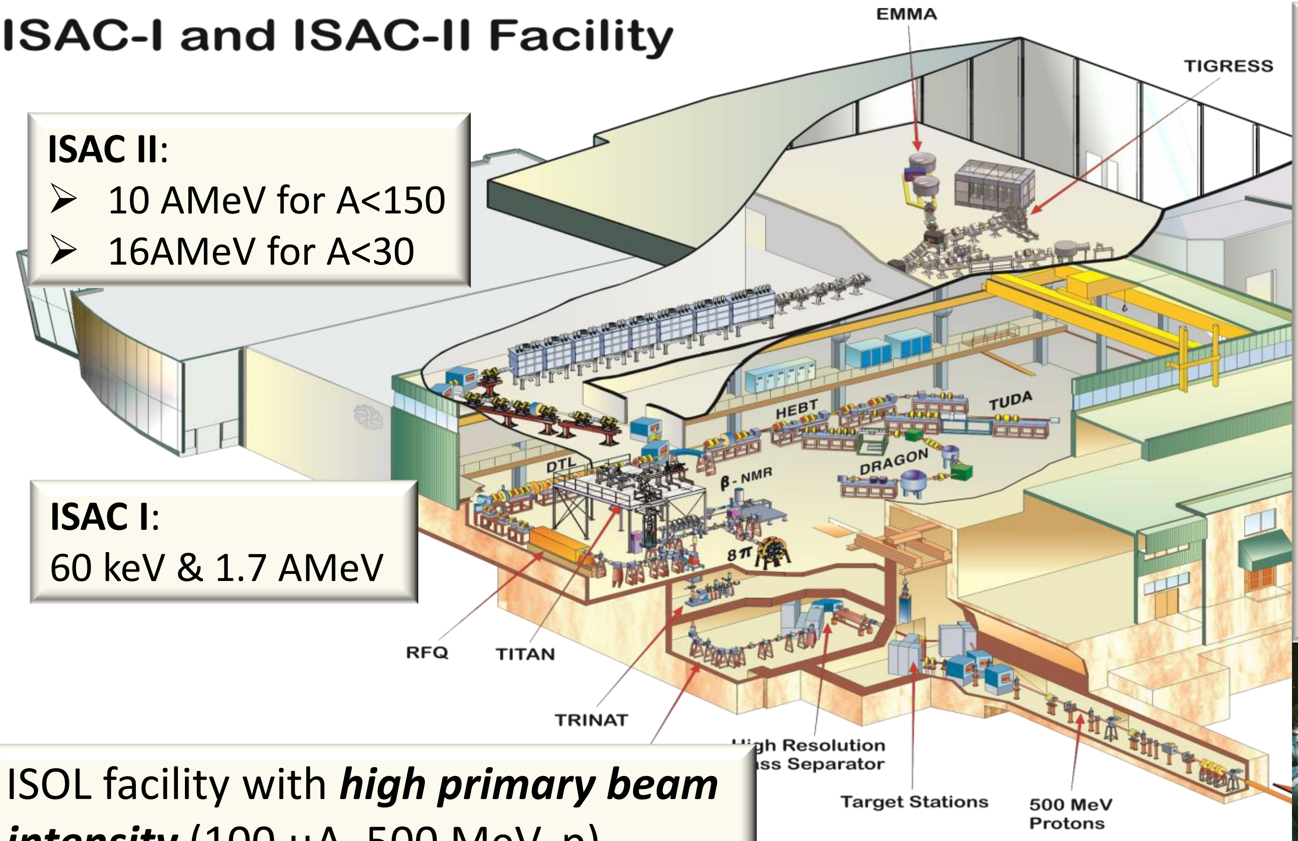
Nordion
commercial medical isotope production
3 cyclotrons

Cyclotron
500 MeV
350 μA

Particle Physics
Pienu
Ultra Cold Neutrons

CMMS
Centre for Molecular and Material Science (μSR)

ISAC rare isotope facility

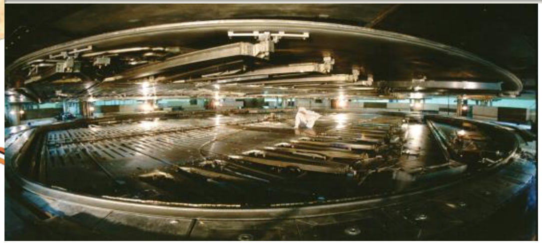


ISAC II:
- ➢ 10 AMeV for A<150
- ➢ 16AMeV for A<30

ISAC I:
60 keV & 1.7 AMeV

ISOL facility with ***high primary beam intensity*** (100 μA, 500 MeV, p)
Operational since 1998.

Programs in
- Nuclear Structure & Dynamics
- Nuclear Astrophysics
- Electroweak Interaction Studies
- Material Science
- 18 permanent experiments



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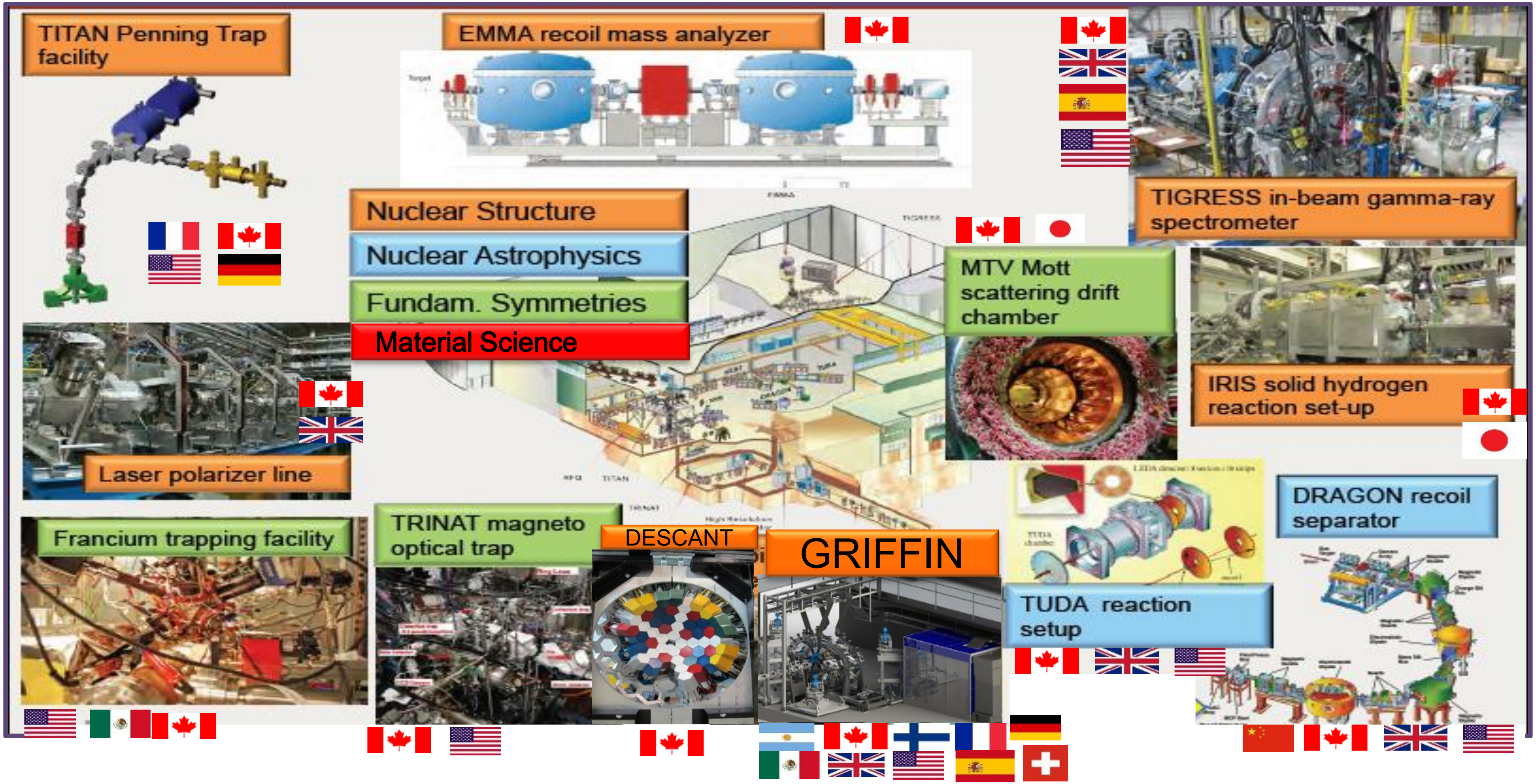
Experimental facilities and programs @ ISAC

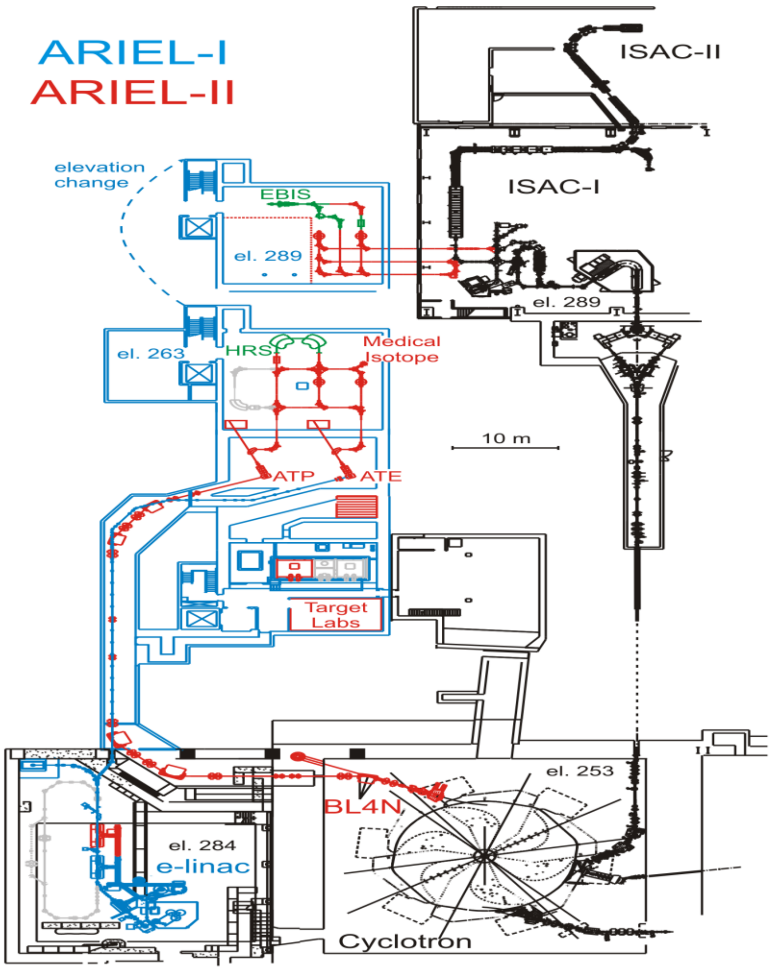


The **A**dvanced **R**are **I**sotop**E** **L**aboratory will triple TRIUMF's isotope beam capacity

- Uses state-of-the-art, made-in-Canada super-conducting electron linear accelerator technology; targets are designed to allow medical isotopes to be extracted alongside the experimental program
- Represents ~$100 million investment by federal and provincial governments; supported by 19 university partners from across Canada
- Project to occur in two phases:
  - ARIEL-I completed in Fall 2014;
  - ARIEL-II funded by Canada Foundation of Innovation, funding announcement imminent.
- Will provide more and new isotopes

TRIUMF ARIEL
ADVANCED RARE ISOTOPE LABORATORY

ARIEL



- expand isotope program at TRIUMF with:
  - 3 simultaneous beams (1 ISAC + 2 ARIEL)
    - e-linac and proton beams
  - Increased number of hours delivered per year
  - New isotope species
    - Time for beam developments
    - Clean beam using HRS and new EBIS
  - Enable long beam times
    - Nucl. astrophysics,
    - Fundamental sym. Tests
  - ARIEL is a project in 2 phases
    - ARIEL-1 completed on time and on budget (2014)
    - ARIEL-2 is starting up

The goal of ARIEL: science and opportunities

- **What we can do at ARIEL:**

ISOTOPES

- isotopes for characterizing new materials:
  - ^{8}Li as a sensitive probe for interfaces
- medical isotopes for nuclear imaging and tumor treatment:
  - alpha-emitters like ^{211}At
- isotopes for developing and refining theory for nuclear physics
  - Proton- and electron-induced rare isotopes at the extremes
- isotopes as laboratories to search for new symmetries in nature
  - Heavy proton-induced isotopes, like Fr, Rn and some light electron-induced isotopes: Li
- isotopes: how and where the heavy elements were produced in the universe
  - Very neutron rich isotopes from photo-fission

- **Triple the available beam time: more time for beam developments**

Isotopes for characterizing new material

Putting new materials together and investigate their behavior: magnetism, superconductivity, semiconductors, batteries …

$SrTiO_3$ = non-magnetic insulator

STO

+

$LaAlO_3$ = non-magnetic insulator

LAO

Magical Multilayers

STO
LAO
STO
LAO
STO

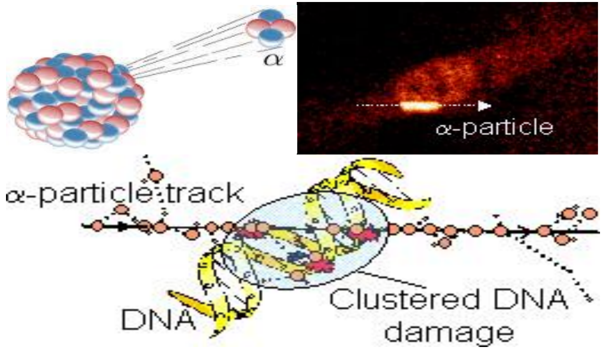
What happens at the interface?
Studies to investigate behavior at the conjunction that is responsible for new effects or features:

- **Need a very sensitive probe for thin layers (~5-10 nm).**

βNMR: uses beta-decay of polarized ^{8}Li to probe for changes in the electric and magnetic fields.
βNMR has unique sensitivity to probe very thin layers (~5-10 nm) to see what happens at the interface by adjusting the implantation depth of the 'heavy ion'.

Isotopes for medical application: tumor treatment and imaging

Alpha emitting isotopes: powerful way for direct tumor treatment

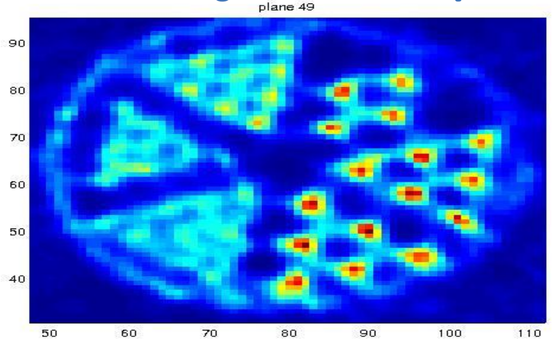


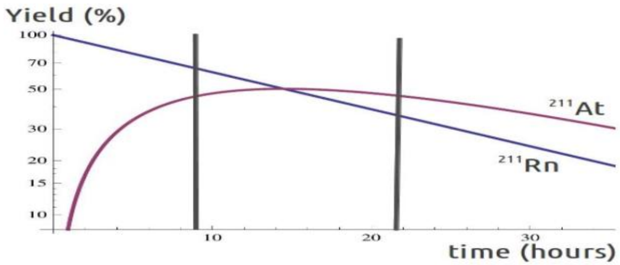
Clustered DNA damage due to
'heavy particle' stopping power, short range.

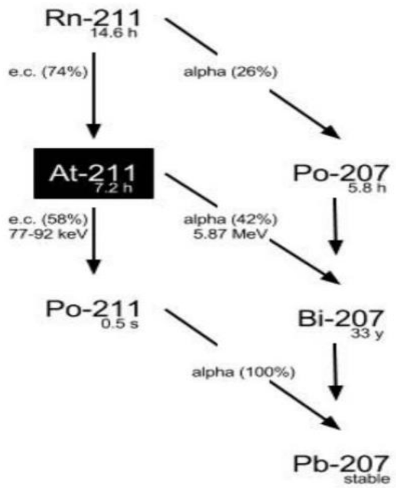
^{211}At particularly well suited for applications
Study surrogate functionality of ^{209}At for imaging

^{211}At is generated via ^{211}Rn at ISAC and ARIEL via protons and could be 'exported' across Canada.

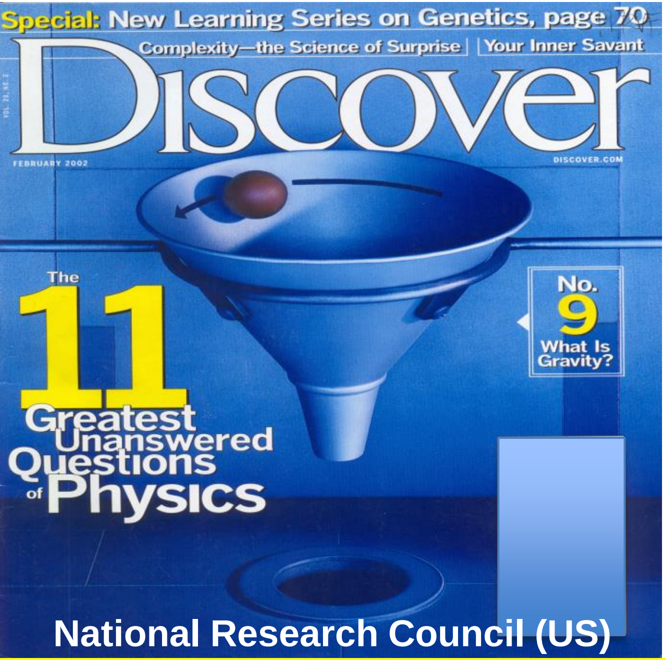
First image with ISAC isotopes





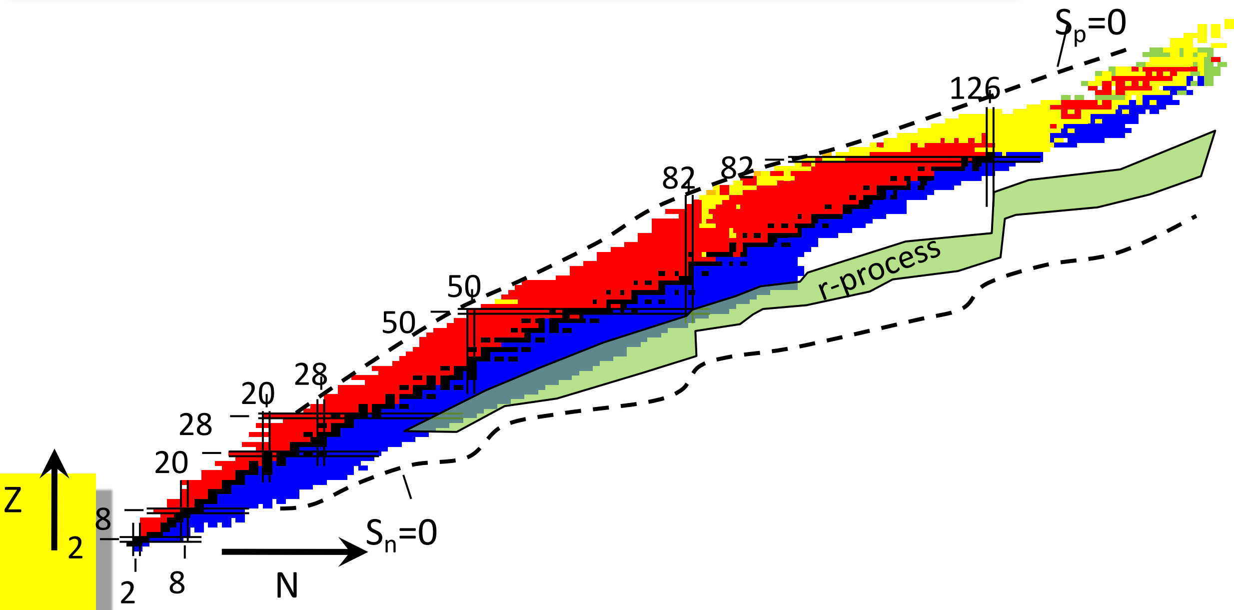


Nuclear Astrophysics: how and where are the heavy elements produced



National Research Council (US)

- **In a 'normal' star, only elements up to iron are produced via nuclear fusion.**
- **How do you generate the heavier elements?**

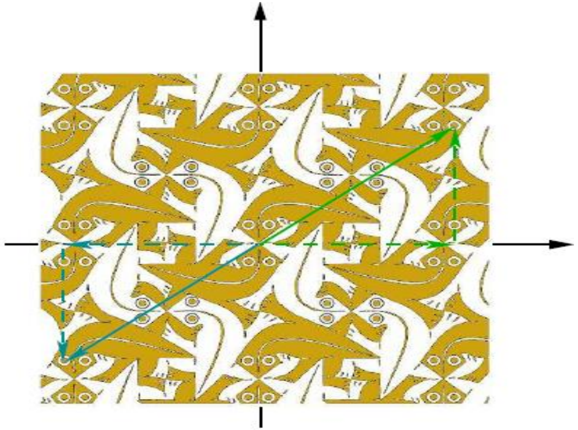


Question 3

How and where were the elements from iron to uranium made ?

Isotopes to search for new symmetries in nature

Nature is governed by symmetry principles

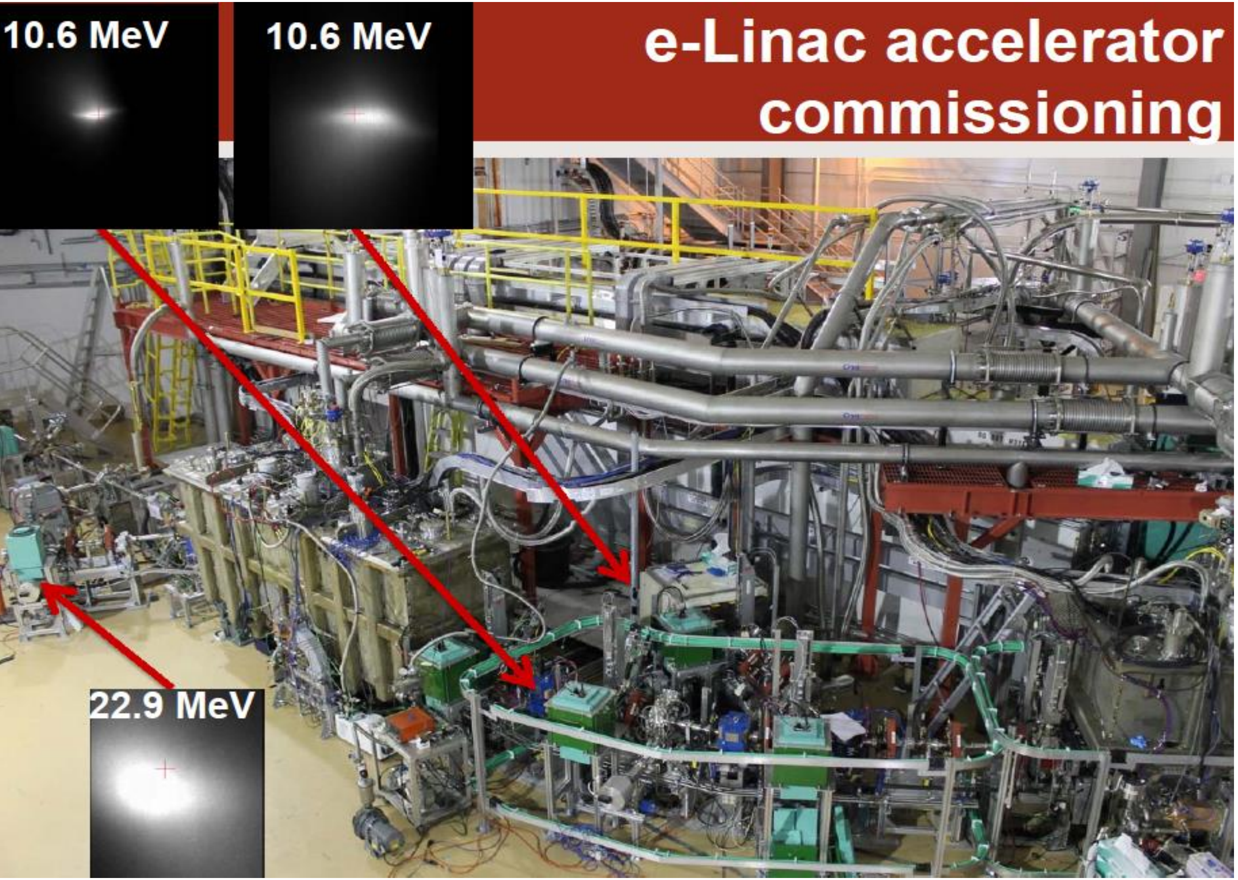


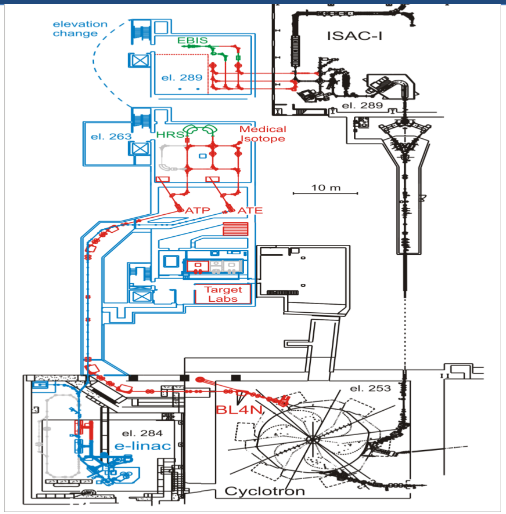
Use synthesized isotopes with ‘special’ features to carry out precision experiments to search for ‘new’ symmetries.

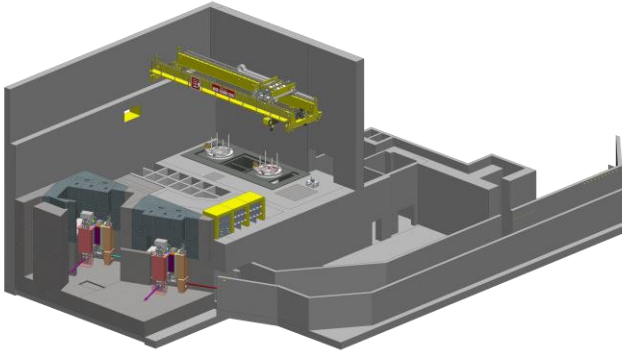
There are multiple symmetry test programs planned (or on-going) at ISAC / ARIEL:

- **Fr atomic parity non-conservation, anapole moment $^{212\ldots}$Fr**
- **Fr permanent electric dipole program $^{208\ldots}$Fr**
- **Rn permanent electric dipole program ^{221}Rn**
- **MTV (Mott polarimetry for time violation): ^{8}Li**
- **TRINAT electro weak symmetry tests ^{39}K**

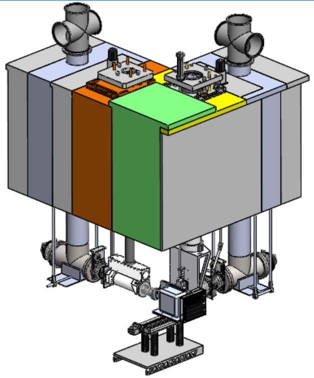
ARIEL-1: e-linac completed and commissioned



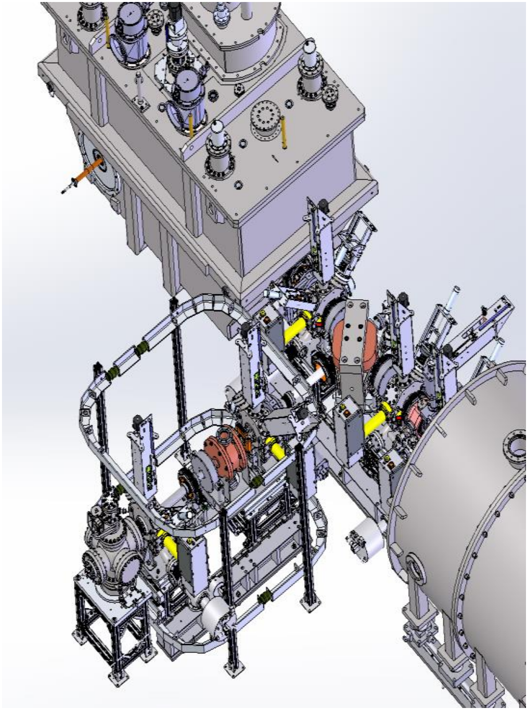


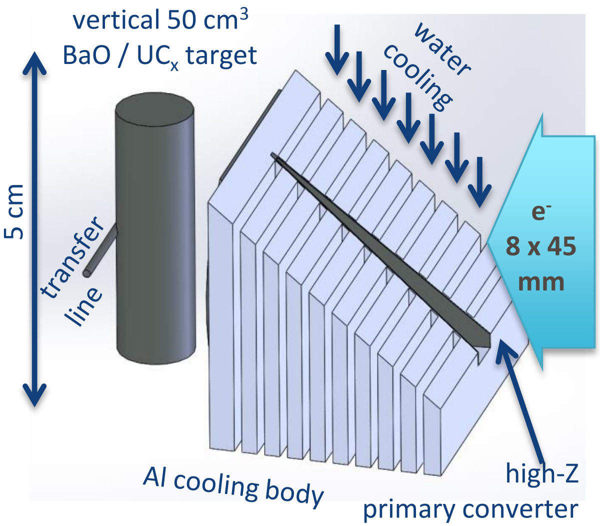


ARIEL-2: developments



- Target developments for p- and γ-fission targets with $^{238}UC_x$ (100kW)
- New target removal and exchange concept (internat. review)
- Test stand for e-hall





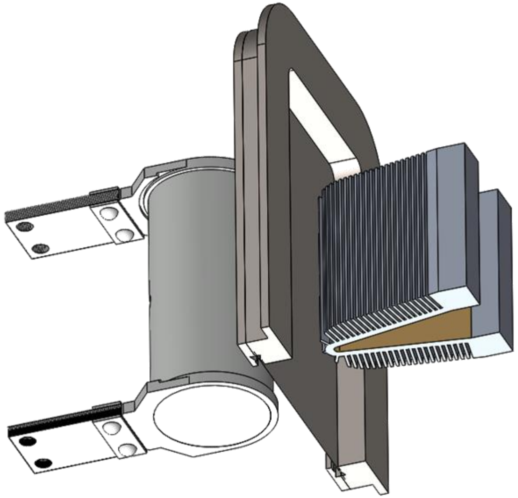


Photo-fission isotopes

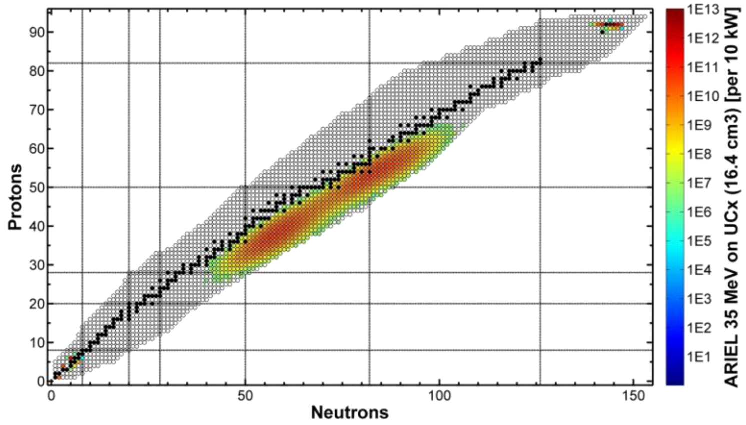
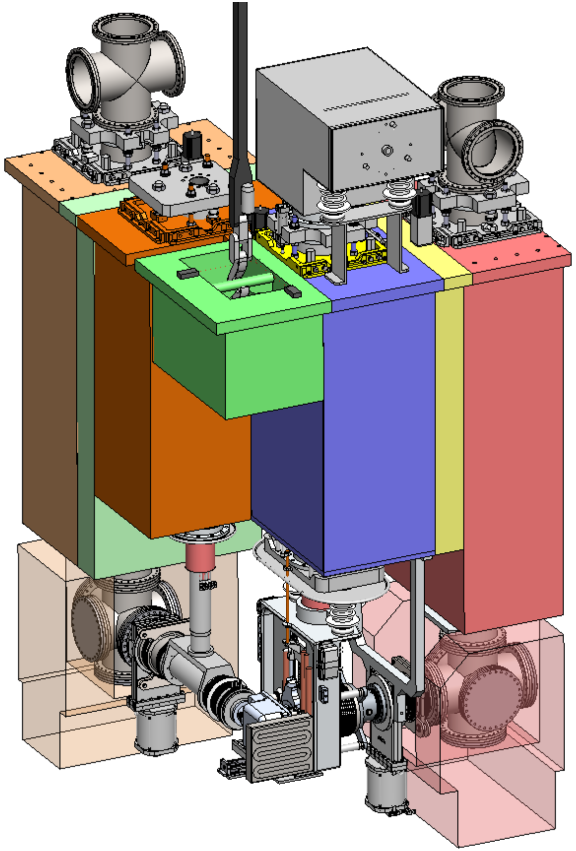


Photo-fission isotopes:

- 'cleaner' n-rich isotopes
- Limited to 100kW targets initially (10^{12} fission)
- Can be achieved with conventional technologies

- Factory model for three beams developed
  - Target exchanges every 3 weeks
  - Storage of targets for up to 3 years
  - New target production capabilities



Modular target system, hermetically sealed units

ARIEL-II Schedule – Science Phases

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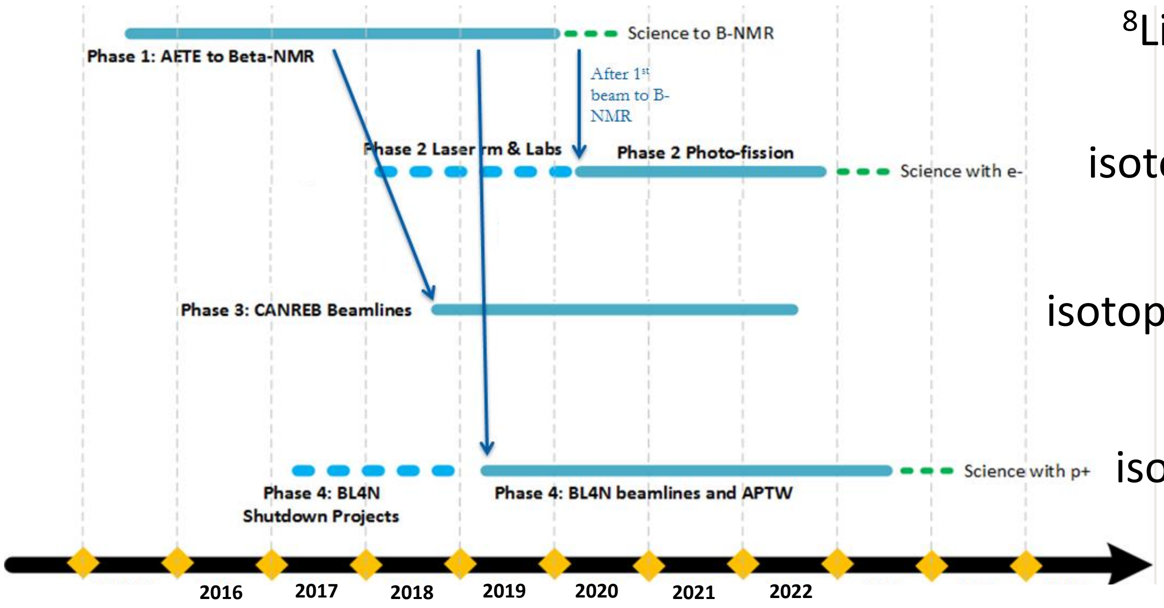

^{8}Li via ^{9}Be(γ,p) using e-linac

isotopes via U(γ,f) using e-linac

isotopes from ISAC, new EBIS and HRS

isotopes via p-induced from ARIEL

Phase	Will deliver isotopes for....
1	Materials science with β-NMR + light beams for Fund. Symmetries. (^{8}Li)
2	Photo-fission of uranium from e-Linac
3	Purified accelerated high mass beams
4	Fundamental Symmetries w/ new proton beamline (BL4N)

ARIEL user consultation ongoing: town-hall meeting in January 2017

Conclusions

ARIEL/ISAC will enable the delivery of three parallel radioactive beams to users:

- Two cyclotron-beams for proton-induced reactions, up to 100 kW
  - Heavy elements for test of symmetries in Nature
  - p-rich beams for fundamental nuclear physics/astrophysics
  - Developments of isotopes for nuclear medicine
- One electron linac beam, up to 100 kW, 35 MeV
  - Photo-fission elements of n-rich beams, astrophysics, nuclear physics
  - Li-beams for material sciences
- Extra time for beam developments

ARIEL will be the first multi-user radioactive beam facility in the world

- Up to three independent experiments
- More time for beam developments

Excellent progress, project is on track:

- Photo-fission target developments under way
- e-beam lines on track, first beam 2019/20
- Proton beam line in preparation
- User consultation on-going

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TRIUMF

Canada’s national laboratory for particle and nuclear physics

Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

TRIUMF: Alberta | British Columbia | Calgary | Carleton | Guelph | McGill | Manitoba | McMaster | Montréal | Northern British Columbia | Queen’s | Regina | Saint Mary’s | Simon Fraser | Toronto | Victoria | Western | Winnipeg | York

Thank you!
Merci!

Follow us at TRIUMFLab

The Future: Science enabled by ARIEL

Actinide proton beam-line:
High intensity, clean beams for electroweak precision experiments using hundreds of days of beam per year
- Francium PNC
- Atomic EDM in Rn
- Electron EDM using Fr fountain

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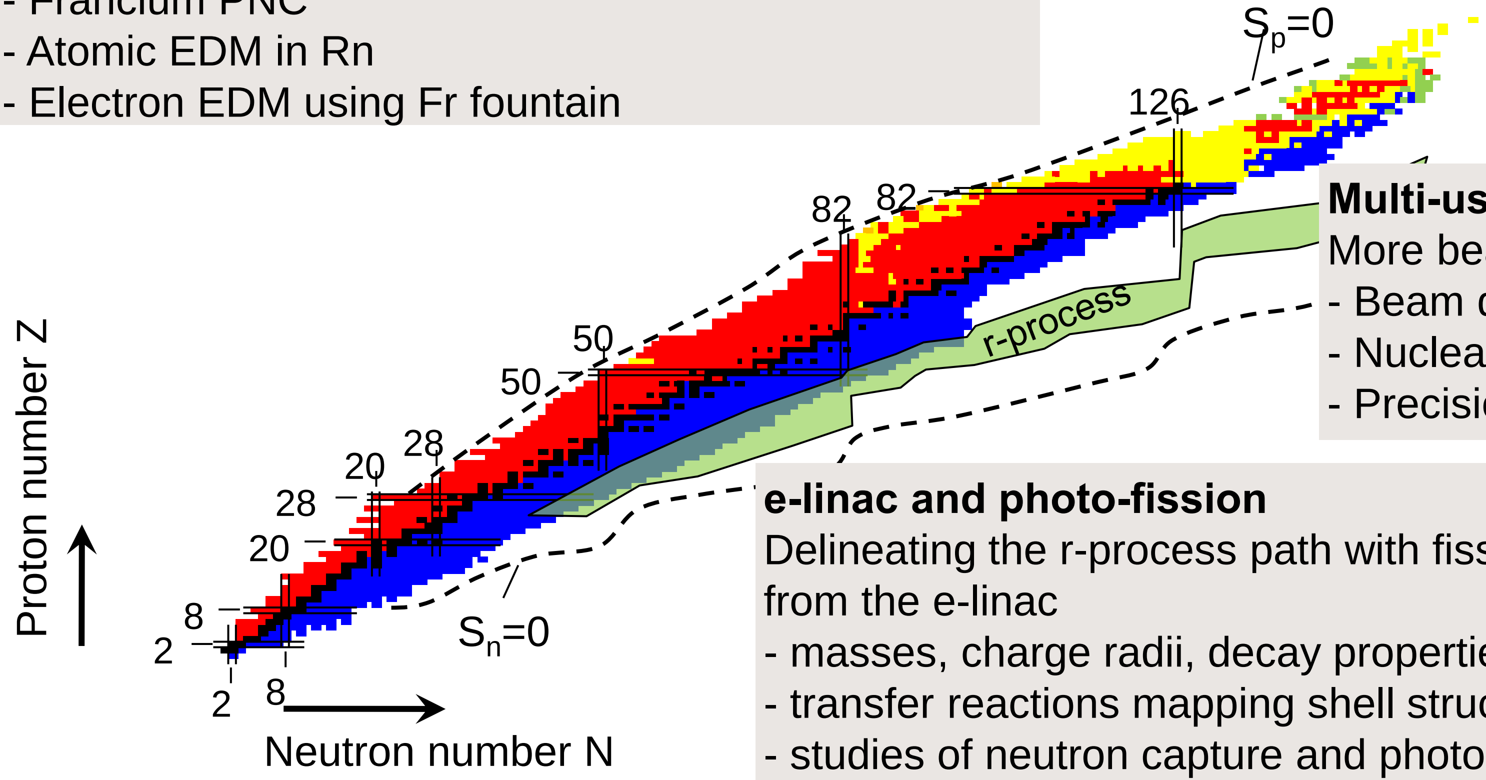

Multi-user operations:
More beam time for
- Beam development
- Nuclear astrophysics
- Precision experiments

e-linac and photo-fission
Delineating the r-process path with fission fragment beams from the e-linac
- masses, charge radii, decay properties
- transfer reactions mapping shell structure
- studies of neutron capture and photo dissociation rates

FLUKA Production Map from 35 MeV Electrons

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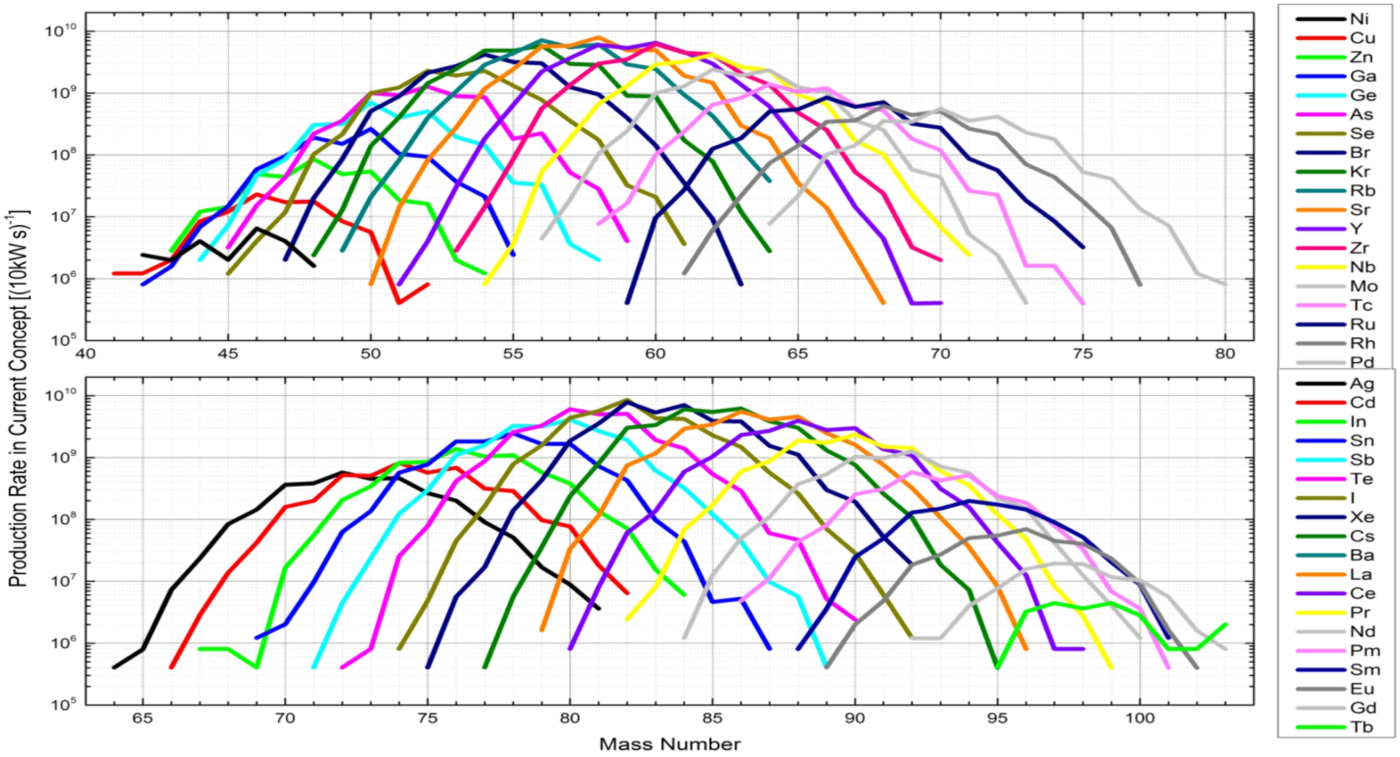
ARIEL Current Concept Design In-Target Production Yields [10 $kW^{-1} \cdot s^{-1}$]



In-target production rates [10 $kW^{-1} \cdot s^{-1}$]:

from BeO:

^{8}Li: $5 \cdot 10^{10}$

from UC_x:

^{78}Ni: $1 \cdot 10^{5}$

^{98}Kr: $8 \cdot 10^{7}$

^{100}Rb: $1 \cdot 10^{8}$

^{98}Sr: $5 \cdot 10^{9}$

^{132}Sn: $5 \cdot 10^{8}$

^{146}Xe: $2 \cdot 10^{7}$

^{144}Ba: $5 \cdot 10^{9}$

^{150}Cs: $4 \cdot 10^{5}$

FLUKA: A. Gottberg (TRIUMF and results verified independently with GEANT4 (Marla Cervantes Smith, University of Victoria)