TRIUMF

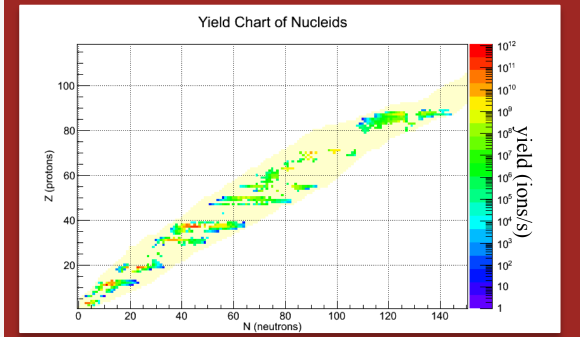
Canada's National Laboratory for Particle and Nuclear Physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

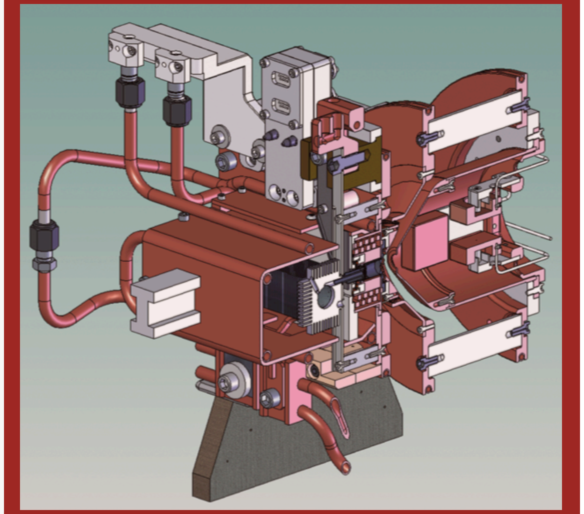
New Generation of ISOL Target Station for Intense RIB

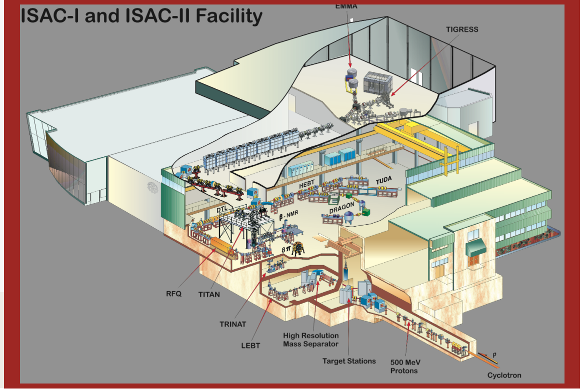
Radioactive Isotope Beam Physics
High intensity, clean, rare isotope beams

Pierre Bricault, Friedhelm Ames, Jens Lassen, Marik Dombsky
| TRIUMF Targets & Ion Sources Dept.

EMIS 2012, Matsue (Japan)







- RIB physics at TRIUMF
- ISOL method for RIB production
- next generation ISOL targets & target station requirements:

increased driver beam intensity

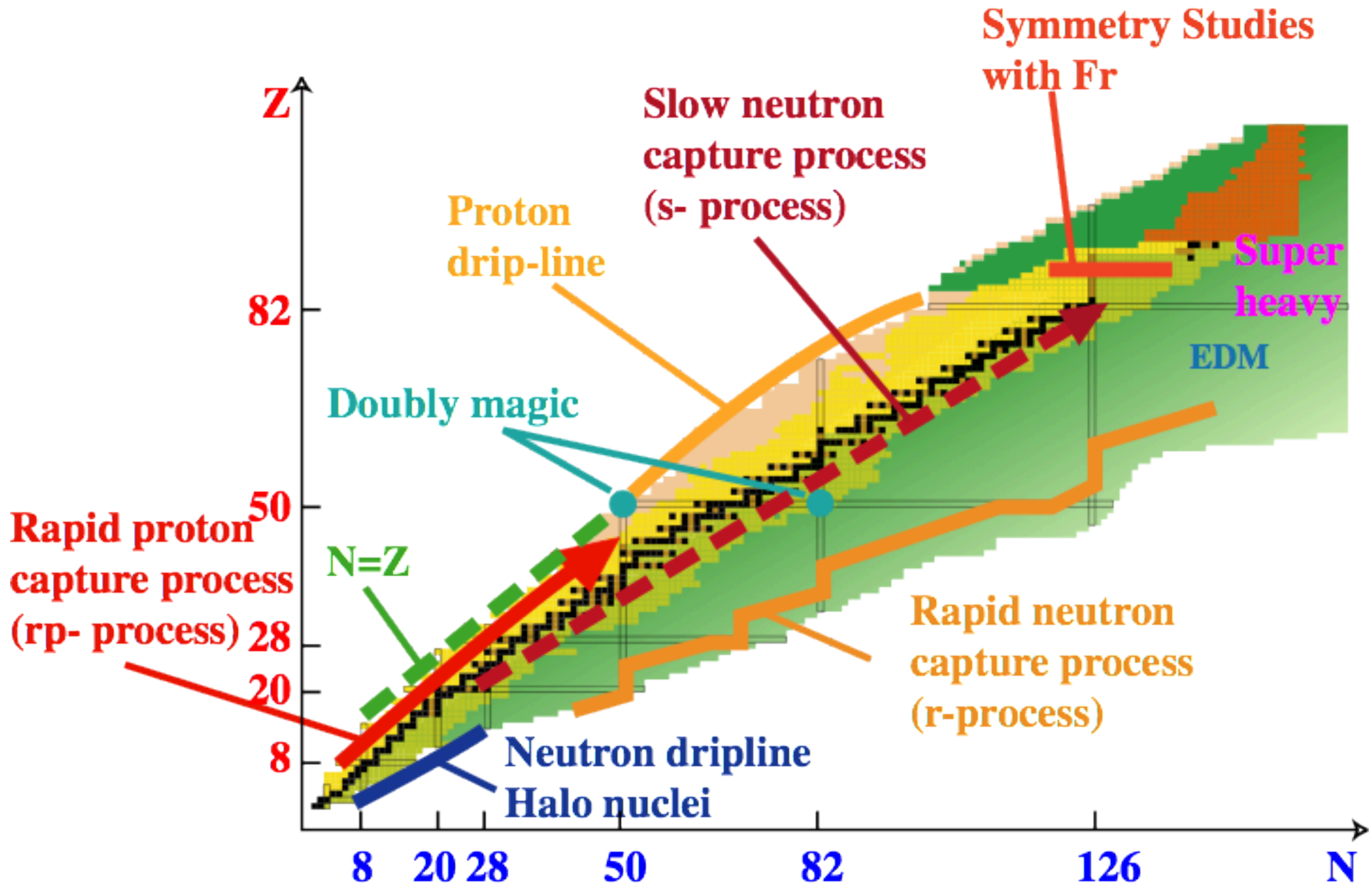
-> high power targets

target materials & UC_x

ion sources

reliabily

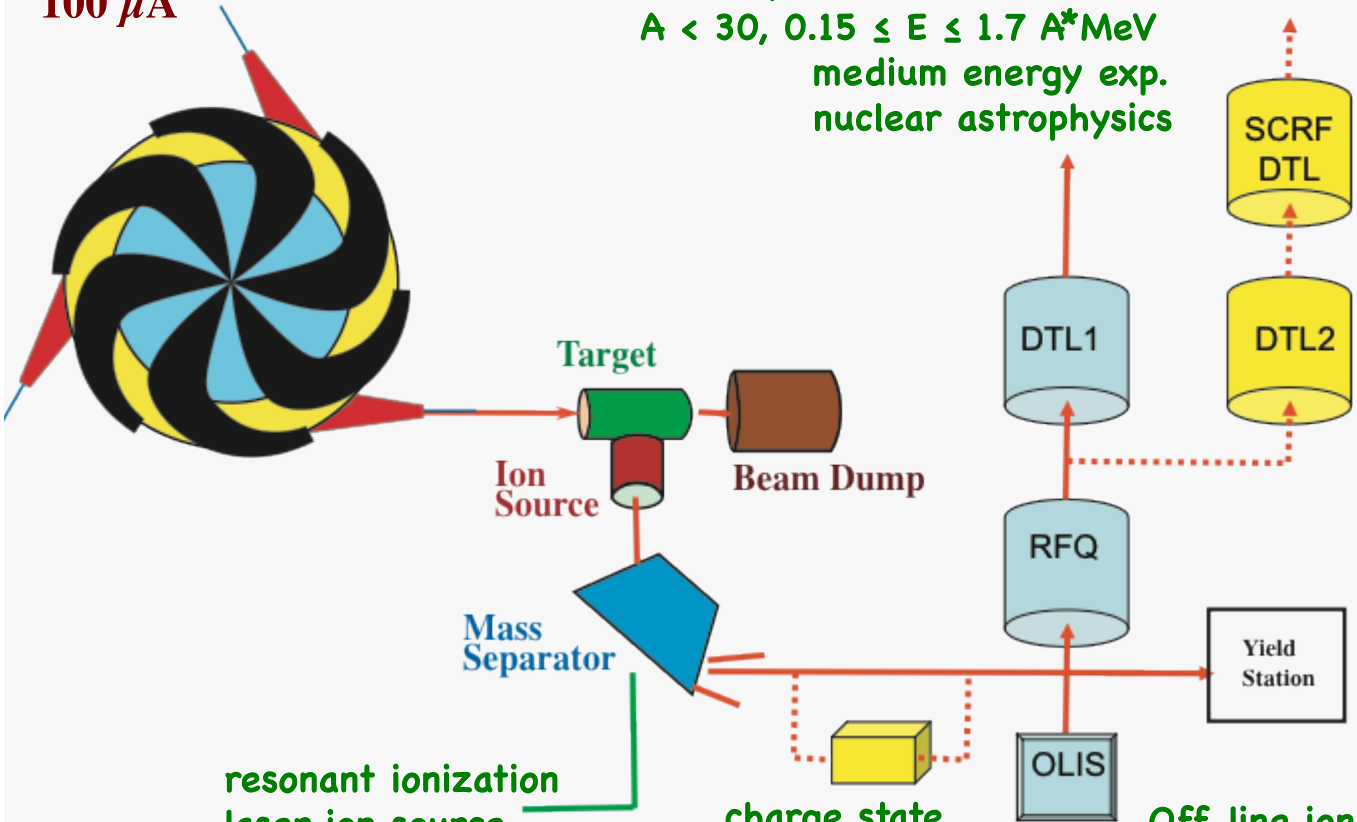
- ARIEL project at TRIUMF, 500 kW e^- on Uc_x


Symmetry Studies
with Fr
Slow neutron
capture process
(s- process)
Proton
drip-line
Z
82
Super
heavy
EDM
Doubly magic
50
Rapid proton
capture process
(rp- process)
N=Z
28
20
8
Rapid neutron
capture process
(r-process)
Neutron dripline
Halo nuclei
8
20 28
50
82
126
N

Driver:
Cyclotron H^-
500 MeV
100 μA

ISAC-II; A ≤ 150, 1.0 ≤ E ≤ 15 A*MeV
High energy exp.
Nuclear structure, nuclear astrophysics, nuclear reactions

ISAC-I;
A < 30, 0.15 ≤ E ≤ 1.7 A*MeV
medium energy exp.
nuclear astrophysics



low energy exp.;
neutral atoms trap,
mass meas.,
gamma spectroscopy,
laser spectroscopy,
precise decay meas.

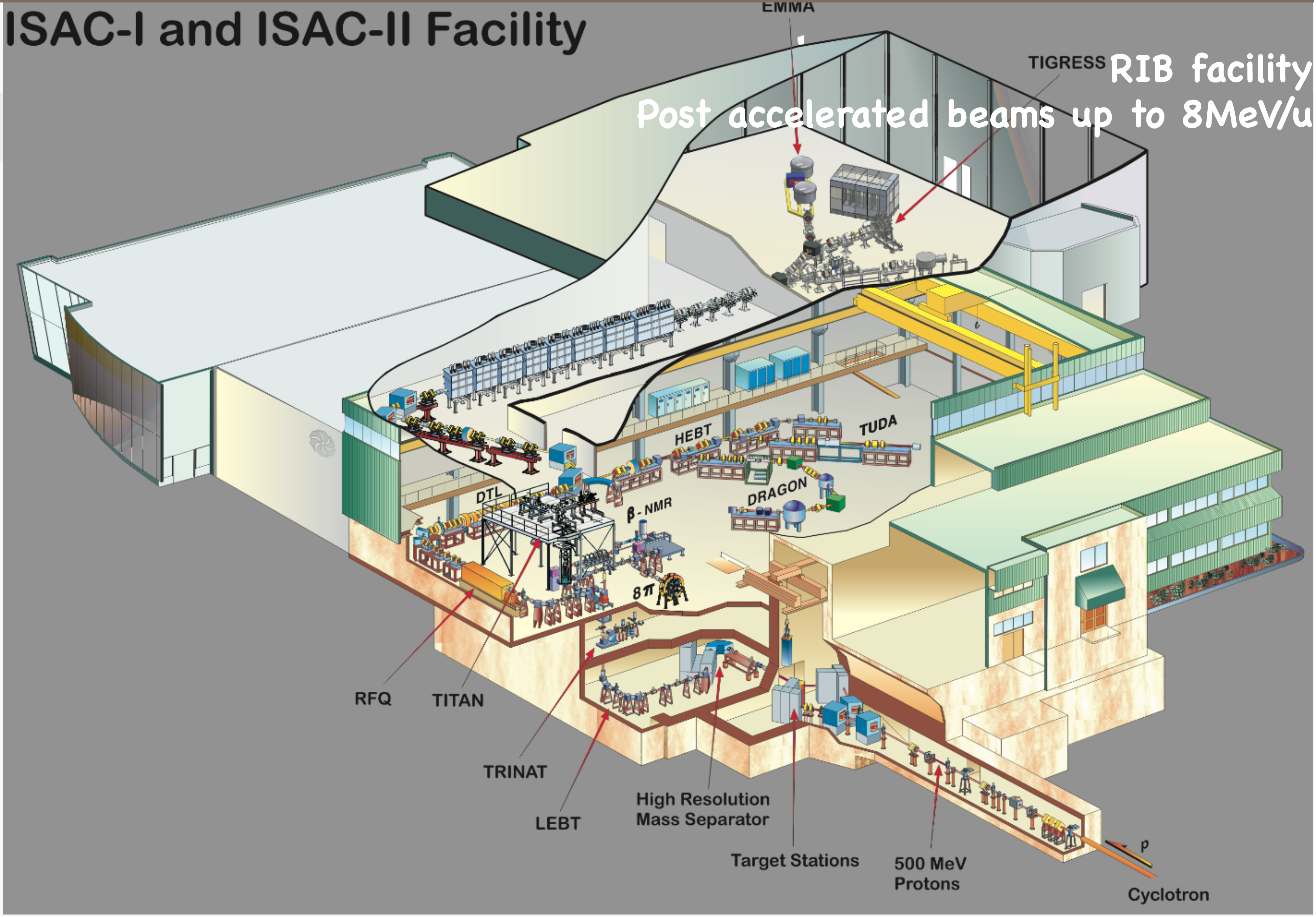
resonant ionization laser ion source

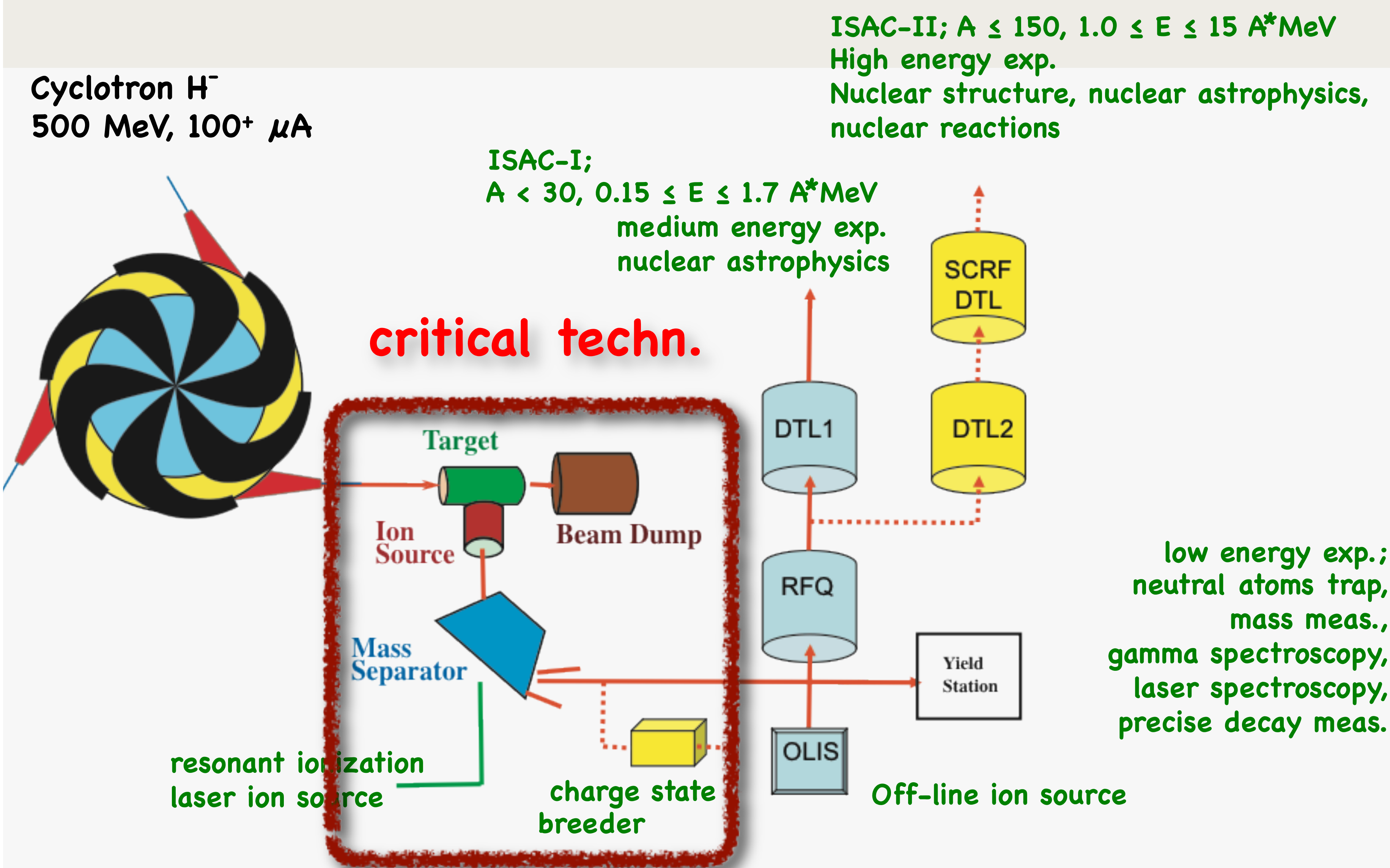
charge state breeder

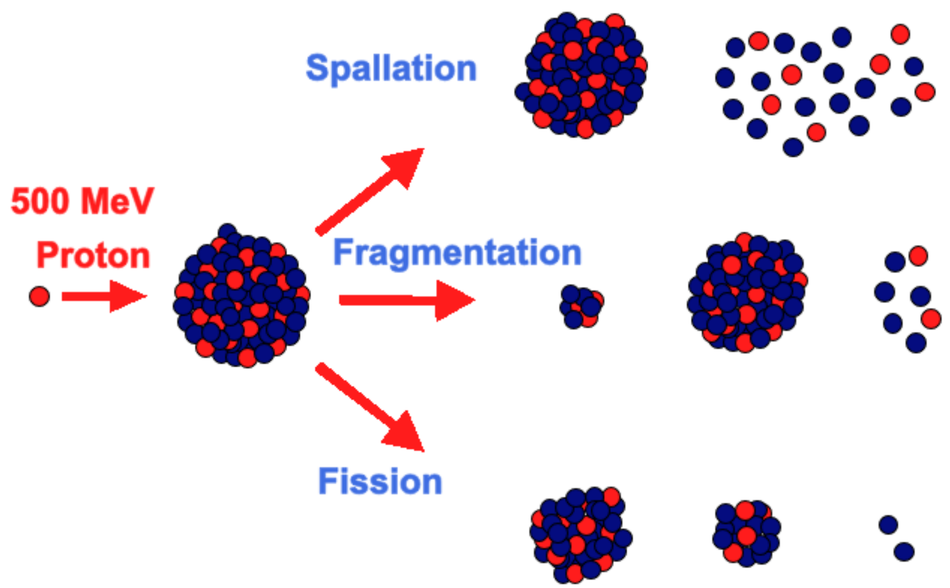
Off-line ion source

ISAC-I and ISAC-II Facility

RIB facility
Post accelerated beams up to 8MeV/u




ISAC-II; A ≤ 150, 1.0 ≤ E ≤ 15 A*MeV
High energy exp.
Nuclear structure, nuclear astrophysics, nuclear reactions
Cyclotron H⁻
500 MeV, 100⁺ μA
ISAC-I;
A < 30, 0.15 ≤ E ≤ 1.7 A*MeV
medium energy exp.
nuclear astrophysics
SCRF DTL
critical techn.
DTL1
DTL2
Target
Beam Dump
Ion Source
RFQ
Mass Separator
Yield Station
low energy exp.;
neutral atoms trap,
mass meas.,
gamma spectroscopy,
laser spectroscopy,
precise decay meas.
resonant ionization laser ion source
charge state breeder
OLIS
Off-line ion source



spallation product distrib. peaks a few mass units lighter than target.

-> n-deficient

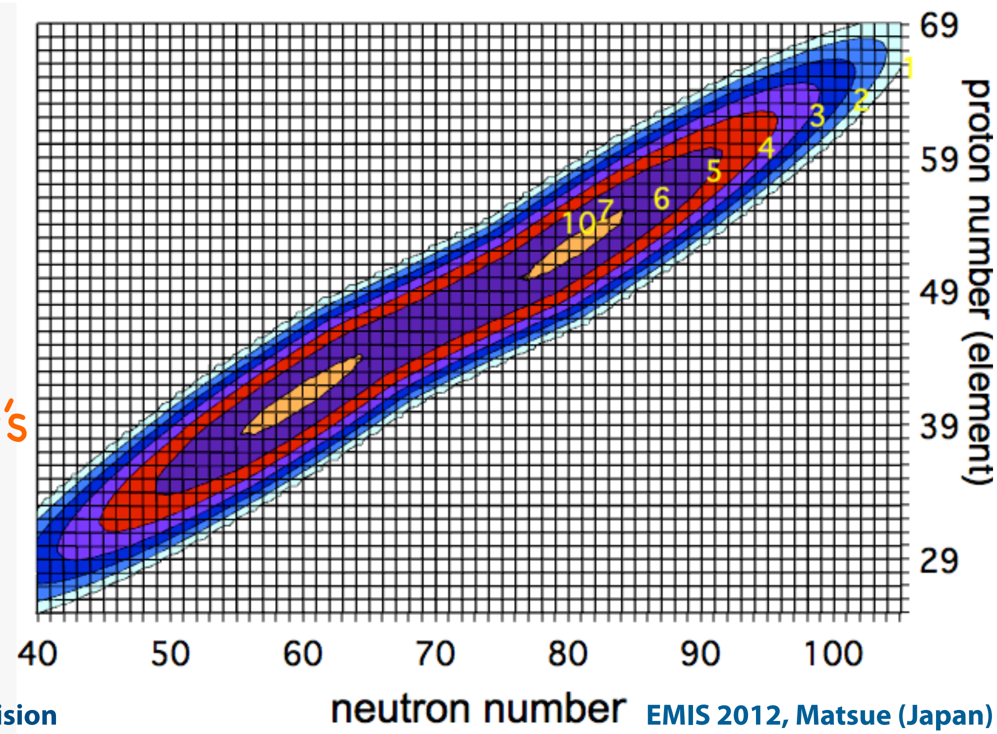
fragmentation product N/Z ratio reflects that of the target (e.g. U, Ta, Nb, Si, Ti) -> n-rich

induced fission yields roughly equivalent mass products.

-> medium range mass-region

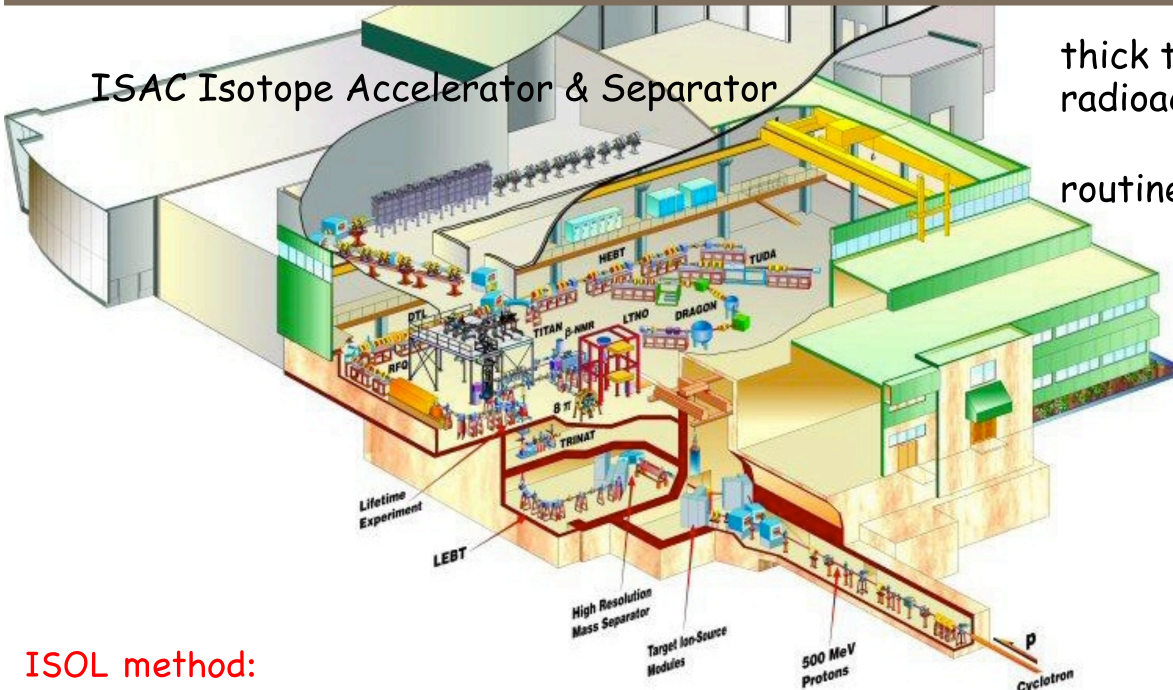
calculated "in-source" production
50 MeV p+ on UC_x

-> drives the "fission/s" facility spec's
-> still needs ion-sources



ISOL concept

ISAC Isotope Accelerator & Separator



thick target – hot cavity ISOL based radioactive ion beam facility

routine operation at the licensing limit:

100 μA p+ on A<81 targets (up to 50kW)
10 μA p+ on UC_x targets
(5 mAh integrated)

RIB beam schedule: Apr.-Dec. (24/7)

ISOL method:

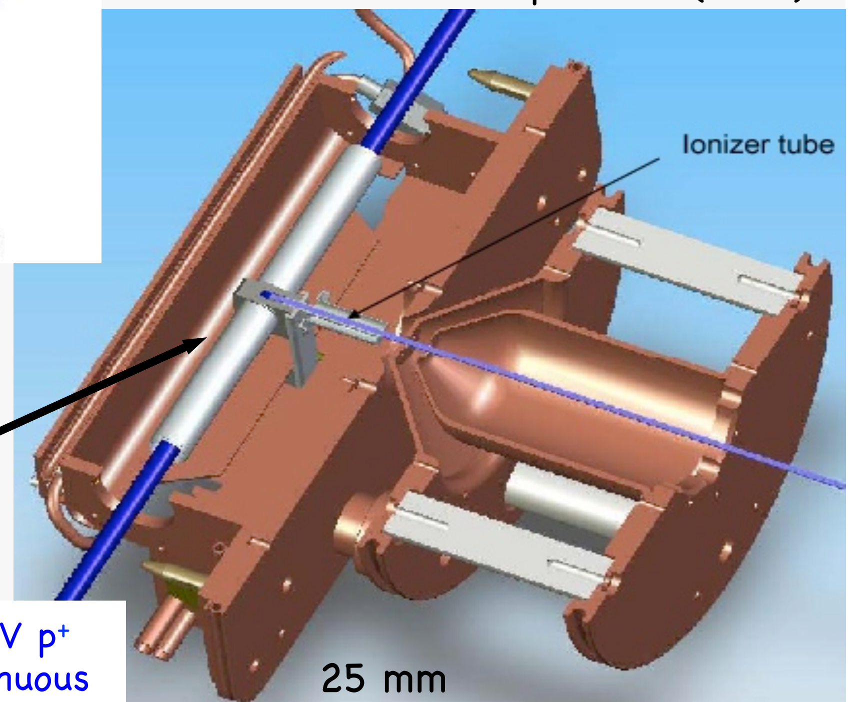
(i) a light ion beam impinges onto a thick high-Z target material,

carbide etc. targets

(ii) the fragments are embedded into the bulk of the target material, metal foil targets

(iii) the fragments are extracted and ionized.

target

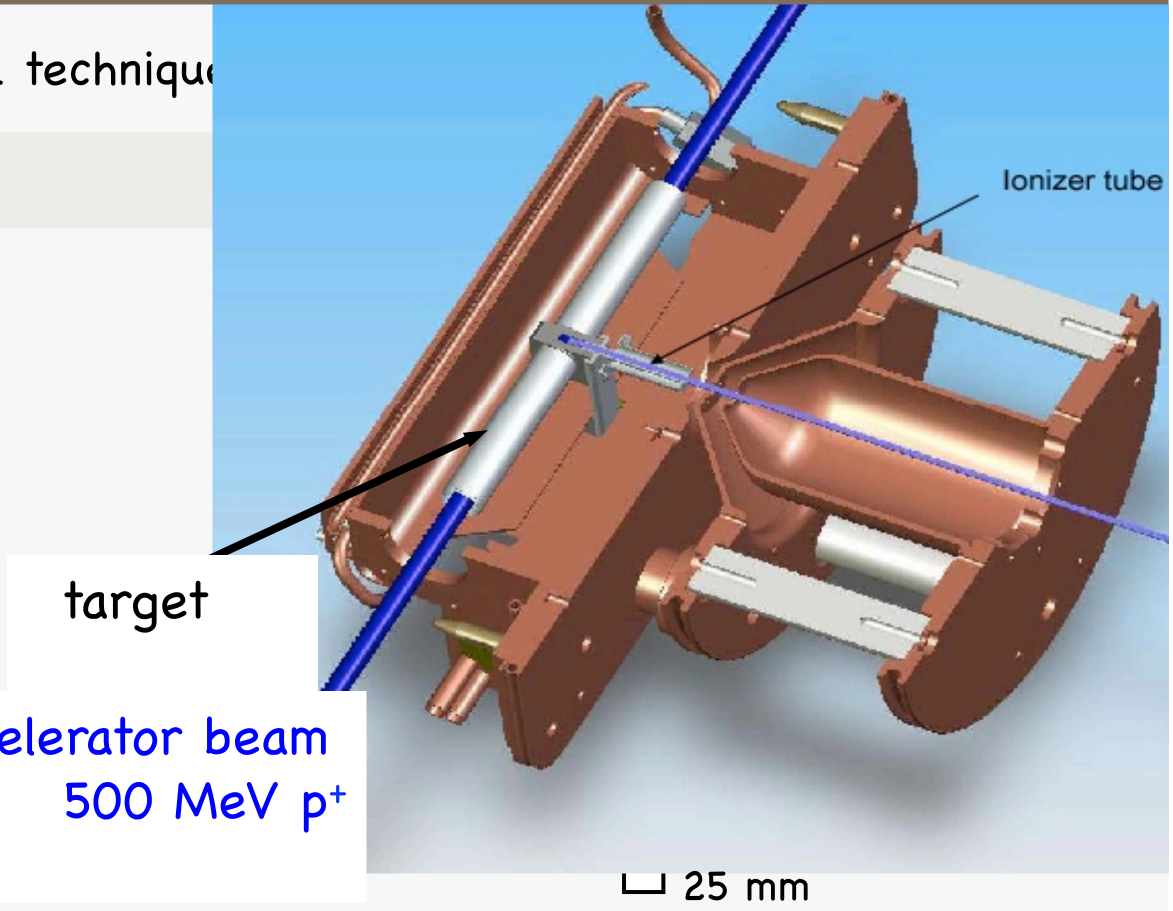


500 MeV p^+ continuous

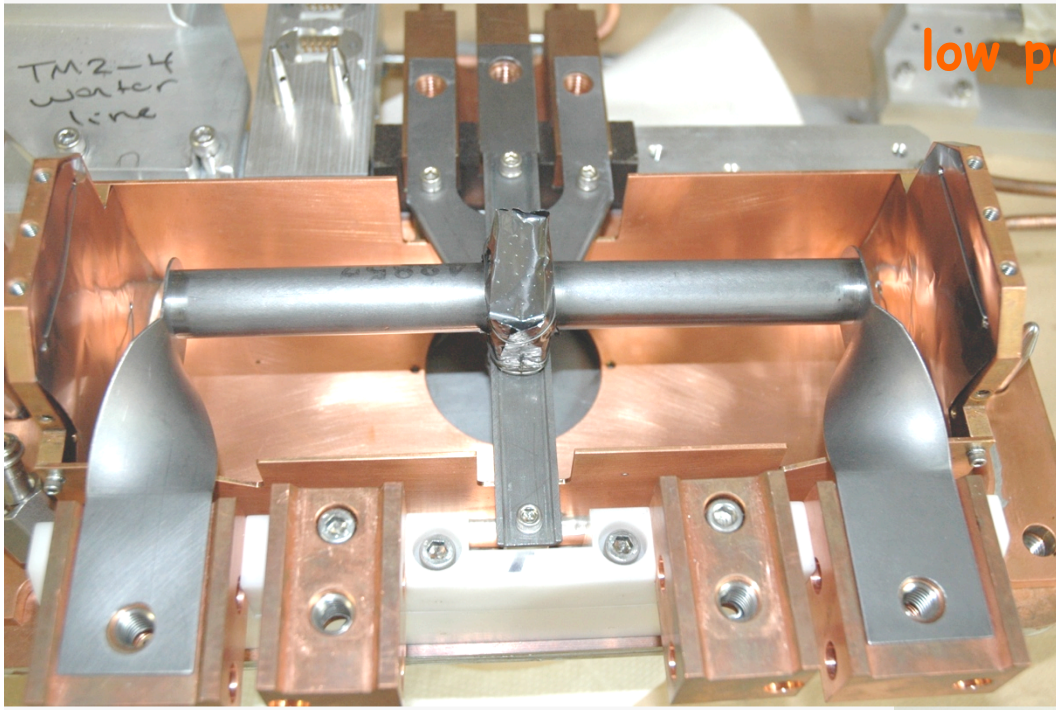
25 mm

Radioactive Ion Beam (RIB) production

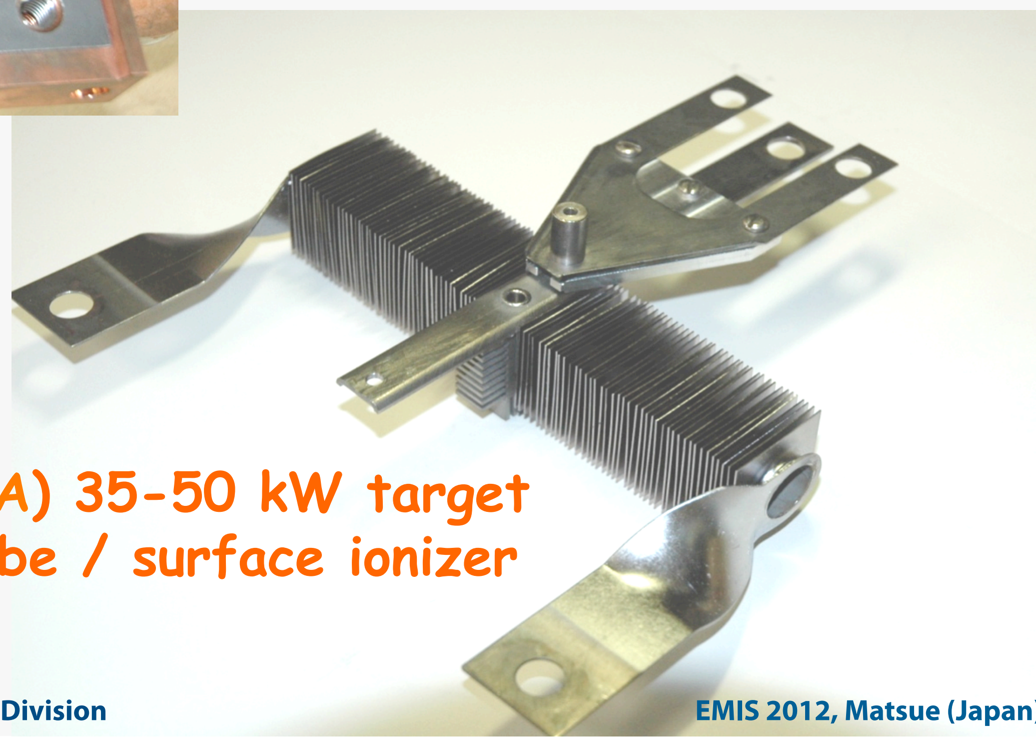
tick target - hot cavity ISOL technique



I isotope separator on-line

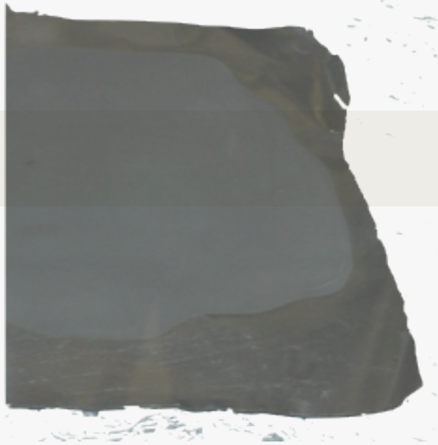


low power ($I_p \leq$ 55 μA) 25 kW target
on heat-sink module (opened)



high power (55≤ I_p ≤100 μA) 35-50 kW target
with transport tube / surface ionizer

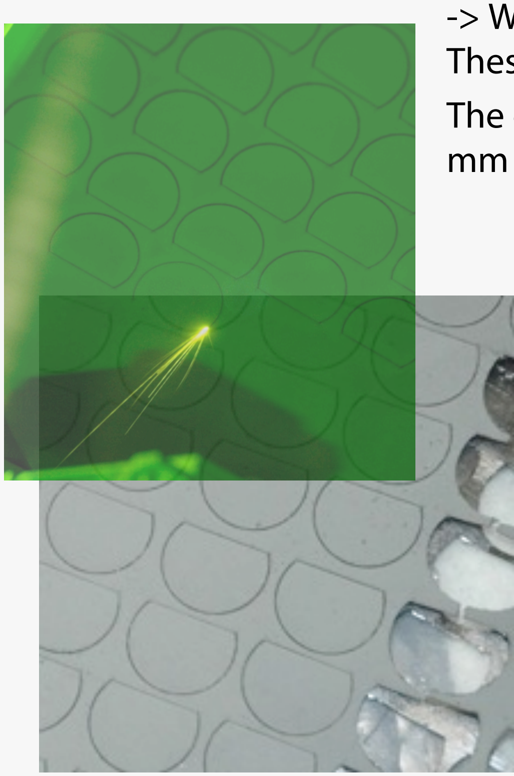
high power target fabrication



(i) ceramic powder suspended in a solvent, which contains dissolved polymers that favor the powder dispersion. This mixture in suspension is poured into a mold or onto a backing foil and then allowed to dry.

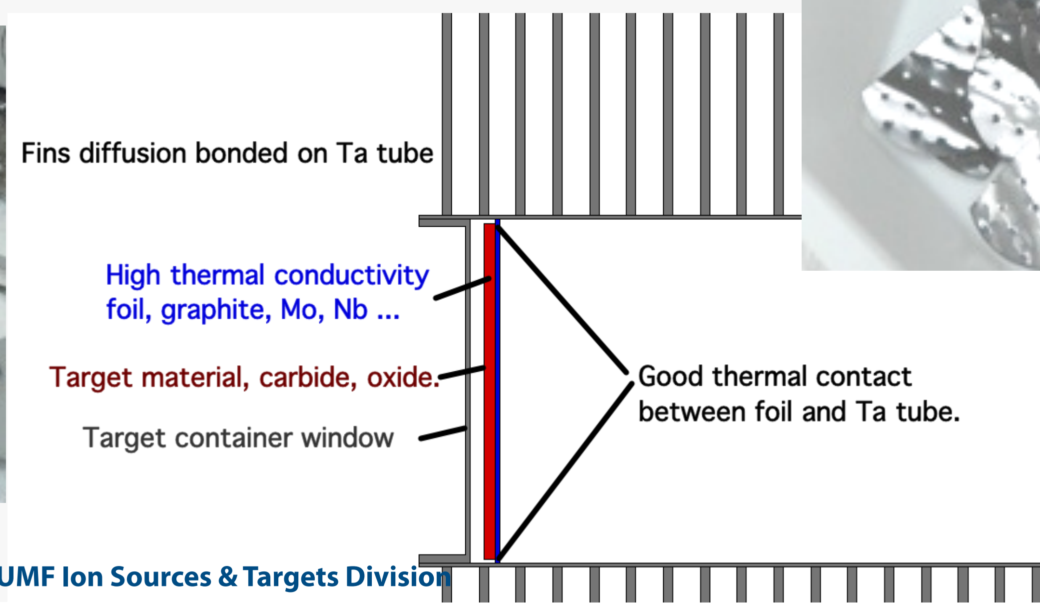
(ii) dried slip cast, with ceramic powder particulates and polymer binders, is easily cut into the desired shape using LASER cutting.

(iii) these carbide ceramics can be used up to 40 µA. Their low thermal conductivity compared to metal foils, necessitates an increase in thermal conductivity of the carbide ceramics to allow targets operation at higher beam intensity.

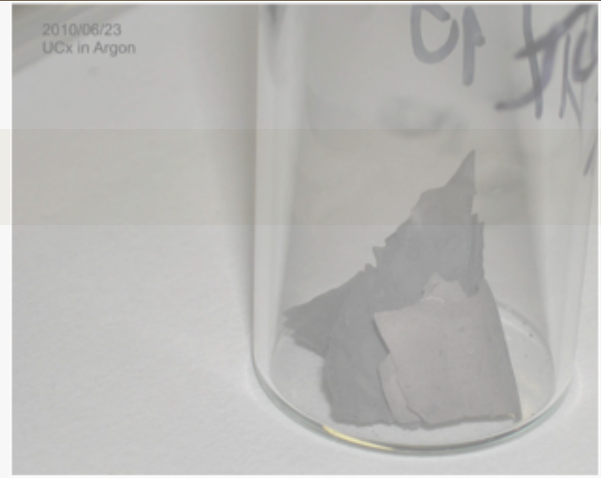


-> We developed ceramic powders and polymers bound to an exfoliated graphite foil. These composite carbide targets are capable of dissipating high power.

The ceramic layer is typically 0.25 mm thick, while the graphite layer is around 0.13 mm thick.



UCx fabrication - the target material



Ucx from UO2 + graphite,

ground to fine power in a plasticiser solution using a ball-mill,

carbonization under vacuum,

sheet is milled in a plasticiser solution again,

solution is cast onto a graphite foil

cut target disks are then cut from the "green" cast

target disks are load into the target container for thermal conditioning (under vacuum).

Ucx advantage:

Good thermal conductivity, compared to UO_2

Low vapour pressure at high temperatures

Concerns:

Exothermic oxidation

operation safety

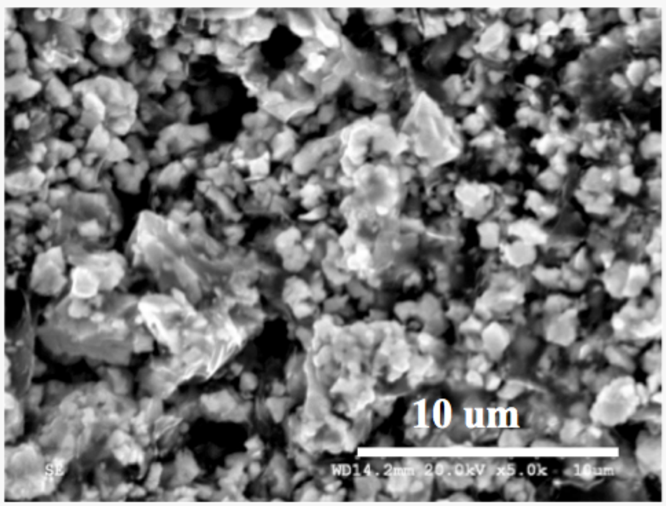
long-term stability after use

storage of irradiated targets

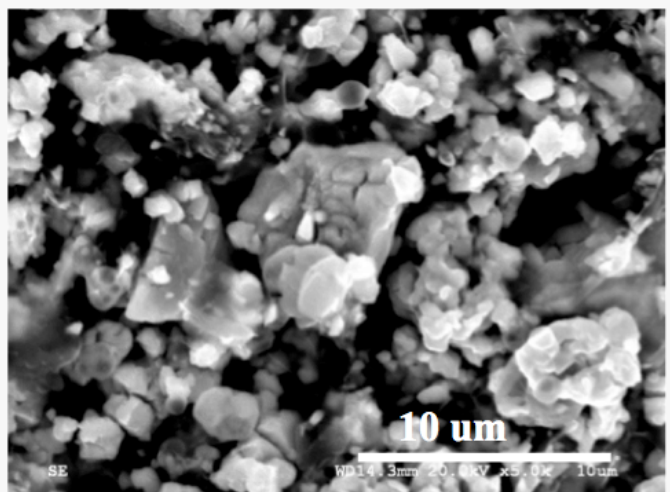
Regulatory:

Handling, inventory,

accounting & envirnomental



"raw" UC_x



sintered UC_x

test chemical stability of UC_x

chemical reactivity in air

Exposed raw and sintered UC_x to air for different periods of time.

Chemical reactivity in air at higher temp.

Heated the raw and sintered UC_x up to 400 degree Celcius.

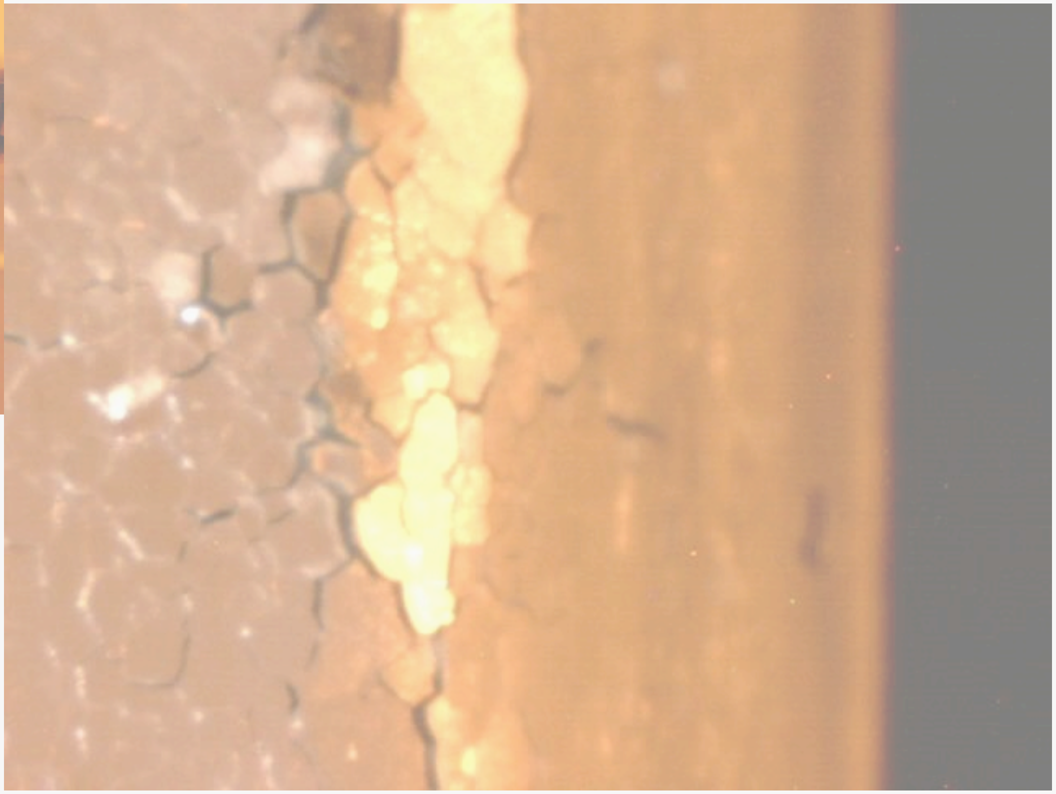
Chemical reactivity in water

Exposed raw and sintered UC_x to water.

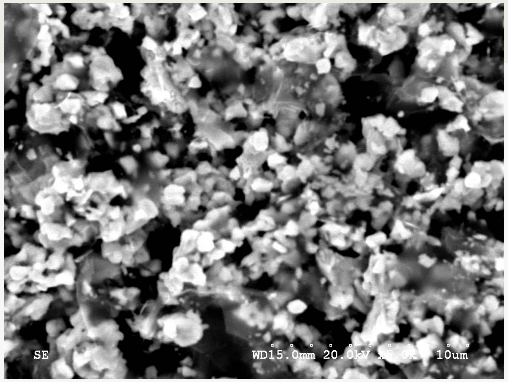
tests show that the UCx material is quite stable and can be used safely within the ISAC operating Environment.

Note>: metallic U is reacts with hot metals

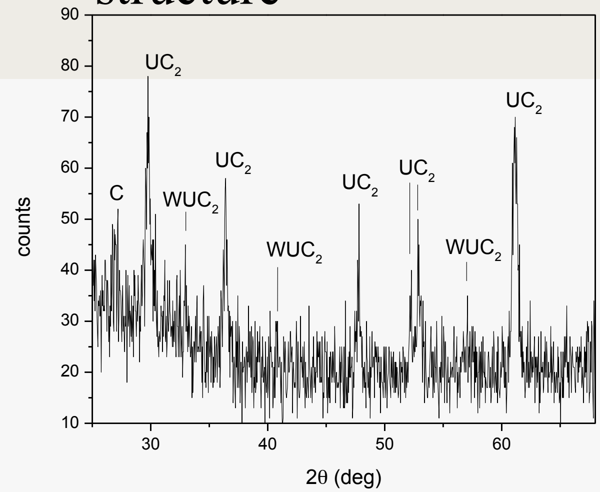
target oven damage – stress & chemistry



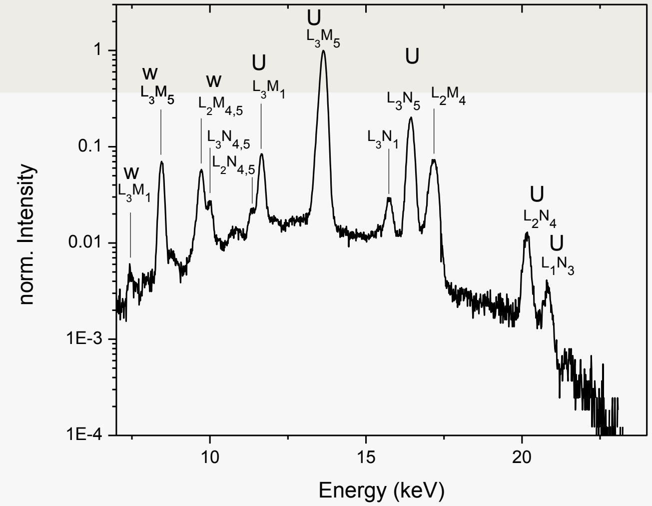
SEM: particle size and porosity



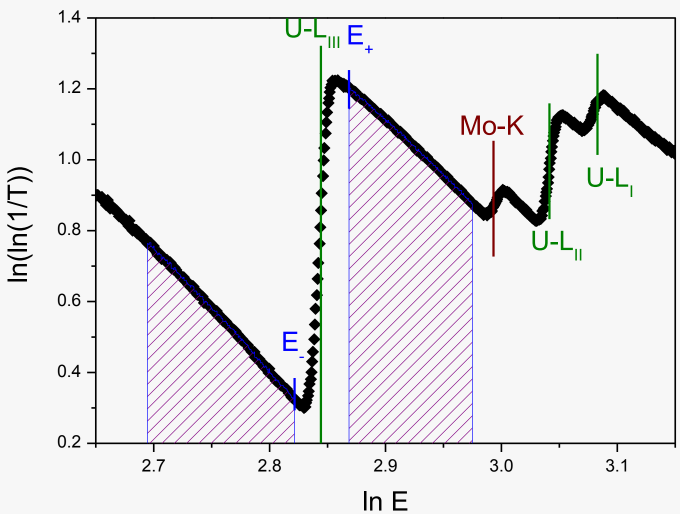
XRD: molecular structure



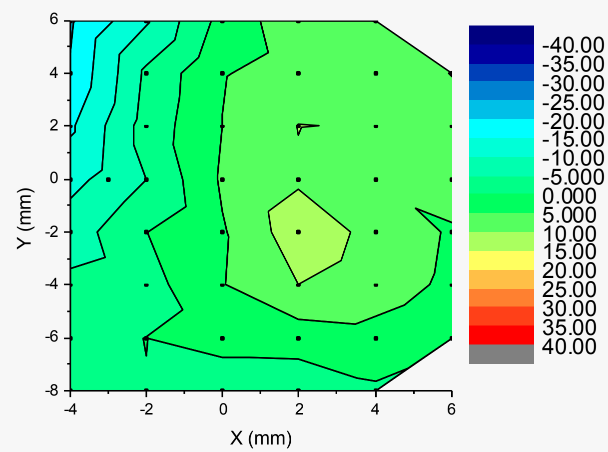
XRF: contaminants



L-edge densitometry (in collaboration with ITU, Karlsruhe)



Spatially resolved thickness measurements on UC_2 target discs

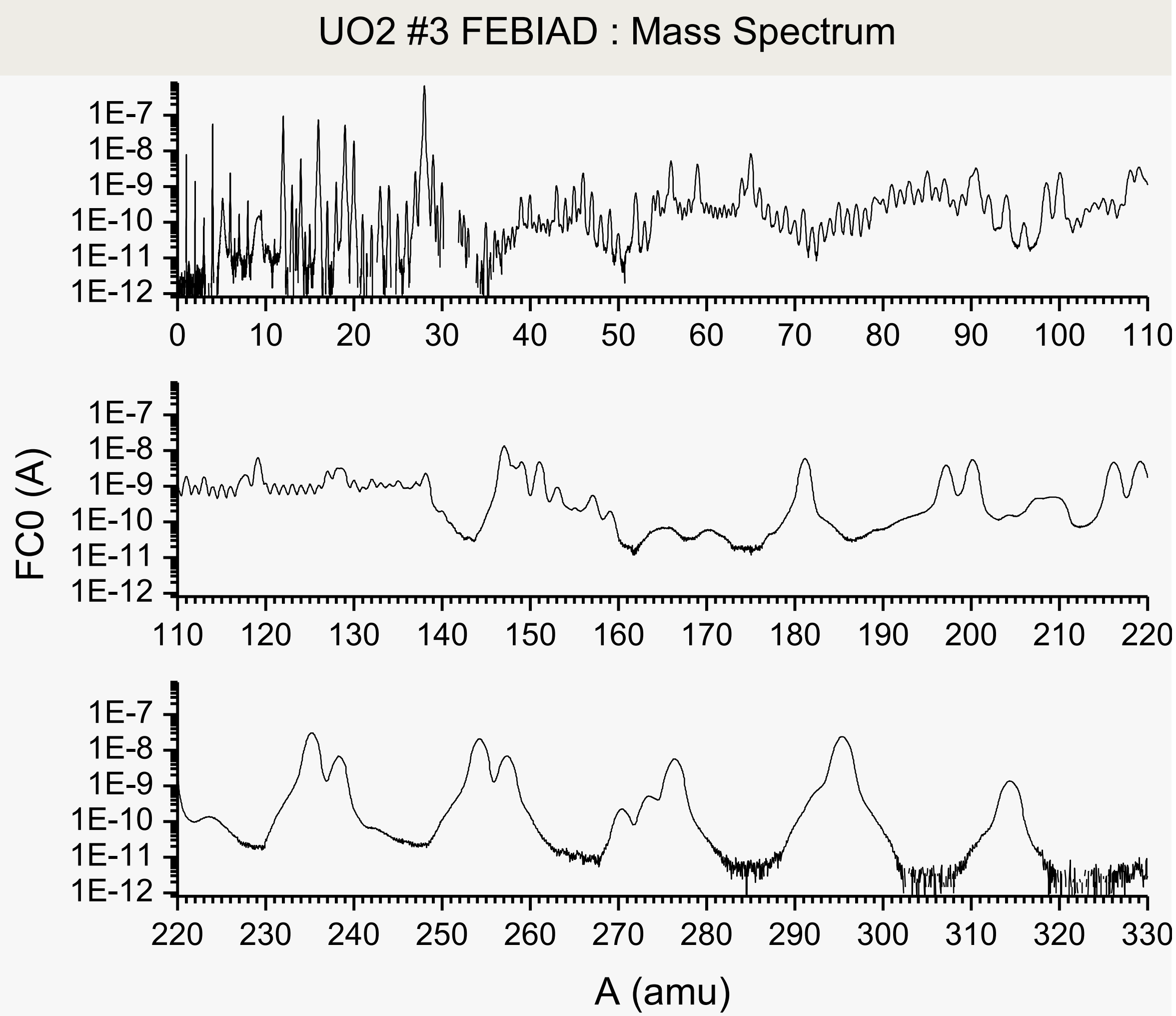


Mass distribution in D-shaped target disc (deviation from mean thickness in %)

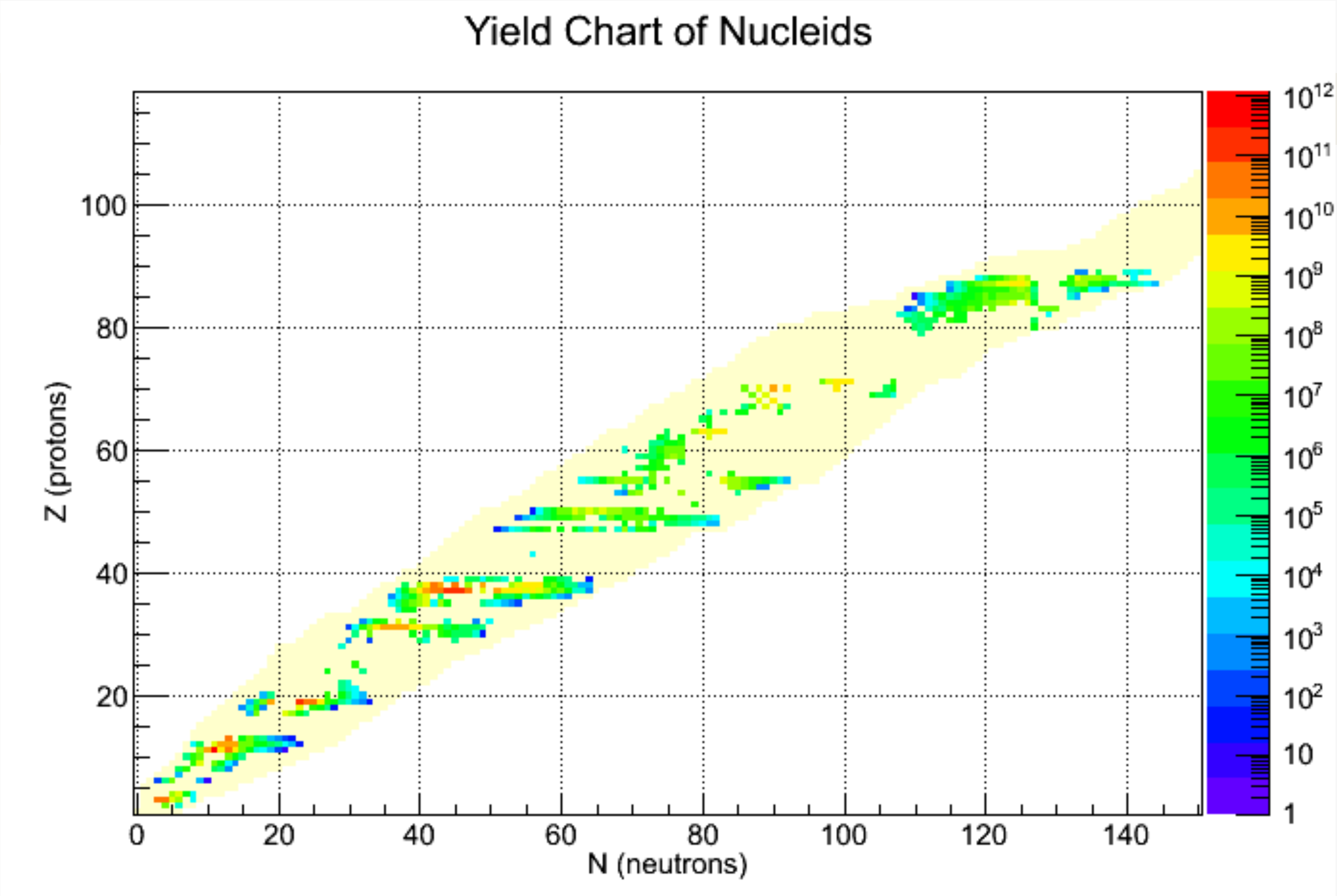
UO_2 target with FEBIAD ion source @ 10 μA

extracted:

He, Li, Na, Xe, Cs,Kr, Rb,
Sr, Zn, Cu, Br, Ga, Ar, K,
Ag, In, Cd,I, Bi, Po, At, Sb,
Rn, Fr, Ra, Cr, Mn, Co, Pb,
Tl, RaF, BaF



Isotopes produced @ ISAC

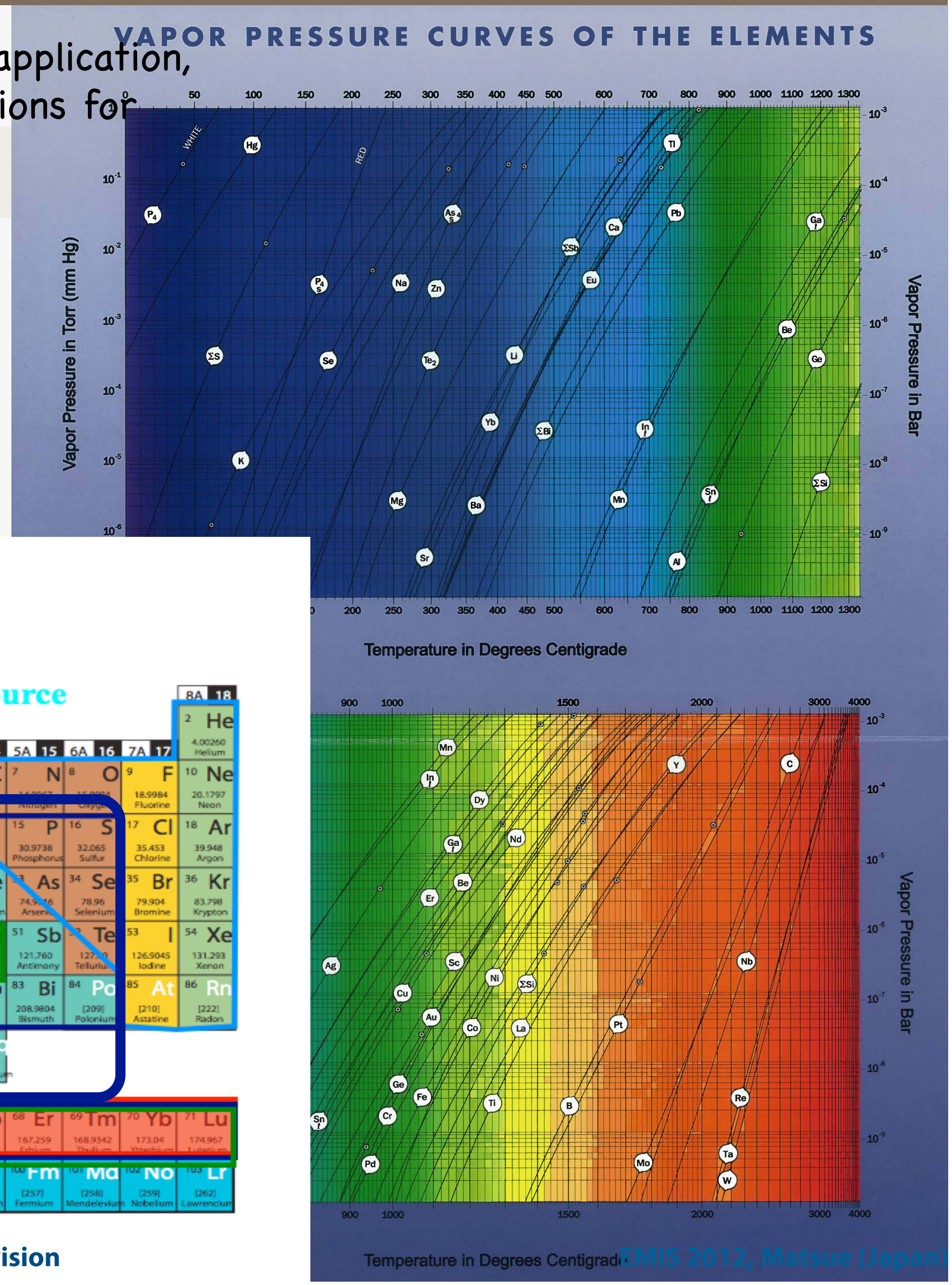


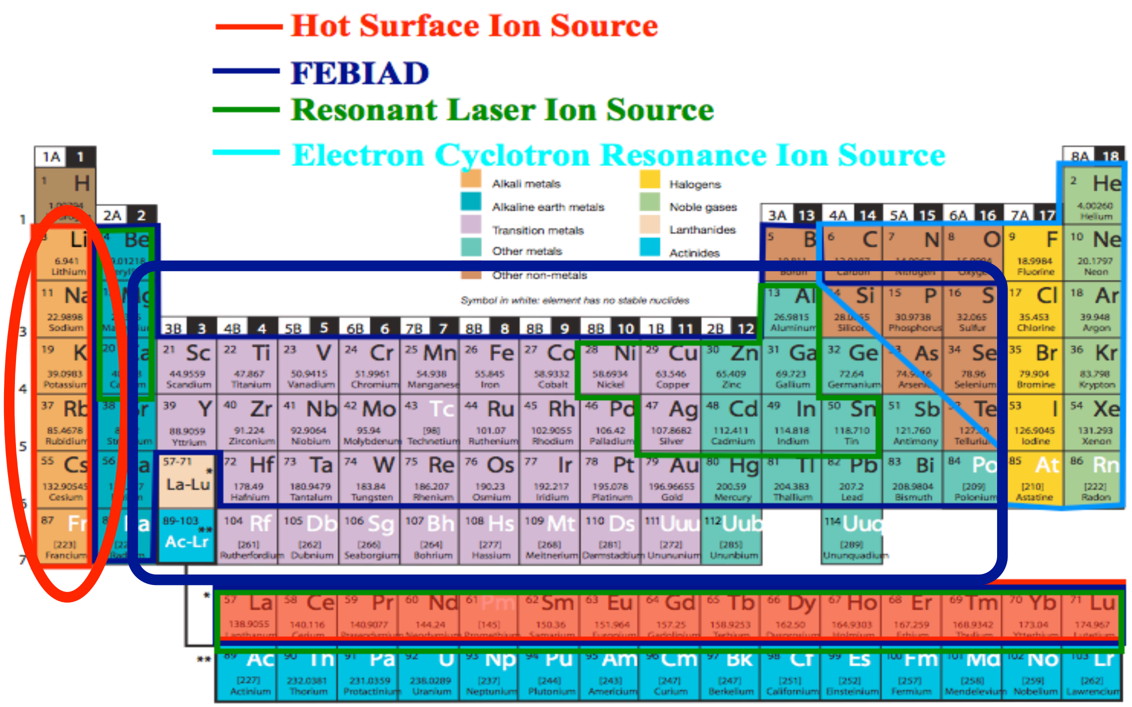
ion Source for High Power Target

There is *no universal* ion source for on-line application,
We must develop target-ion source combinations for each group of elements.

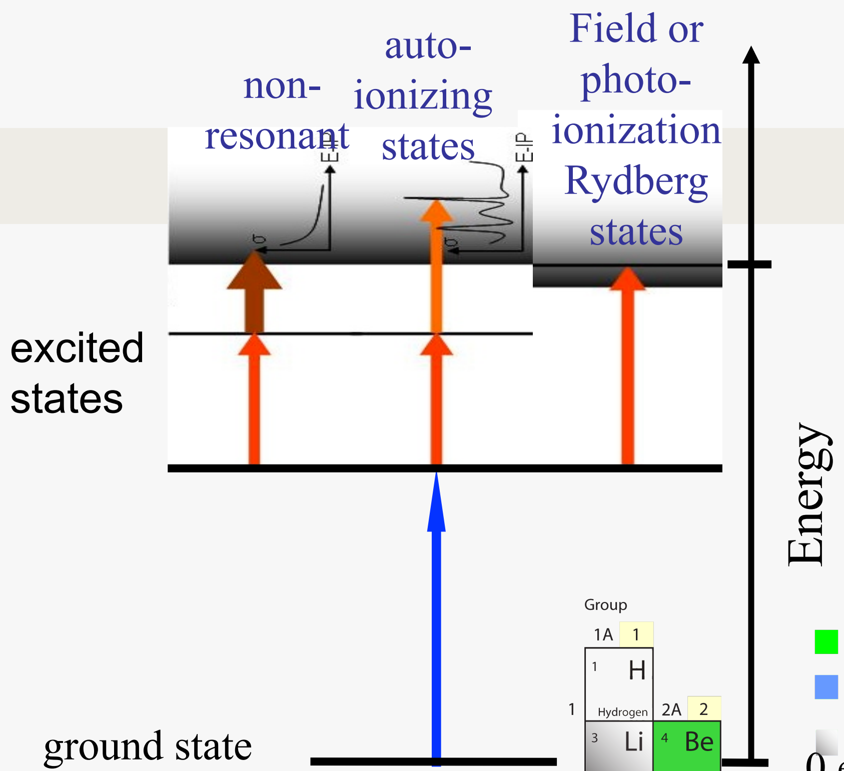
Ion sources:

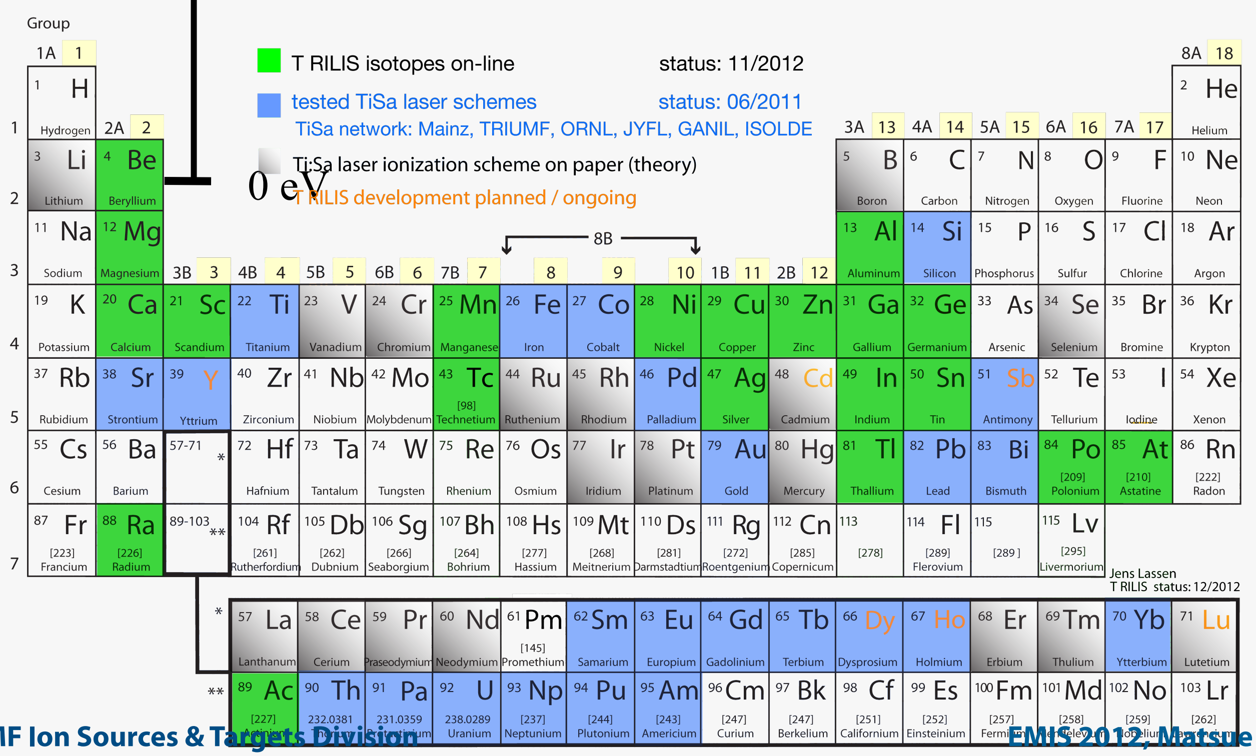
1) Hot surface-
2) Negative-
3) Plasma-, ekectron implact-, ECR-
4) Resonant ionization laser- IS





P. Bricault, M. Dombsky, J. Lassen | TRIUMF Ion Sources & Targets Division


non-resonant
auto-ionizing states
Field or photo-ionization Rydberg states
E-IP
E-IP
excited states
ground state
Energy
0 eV

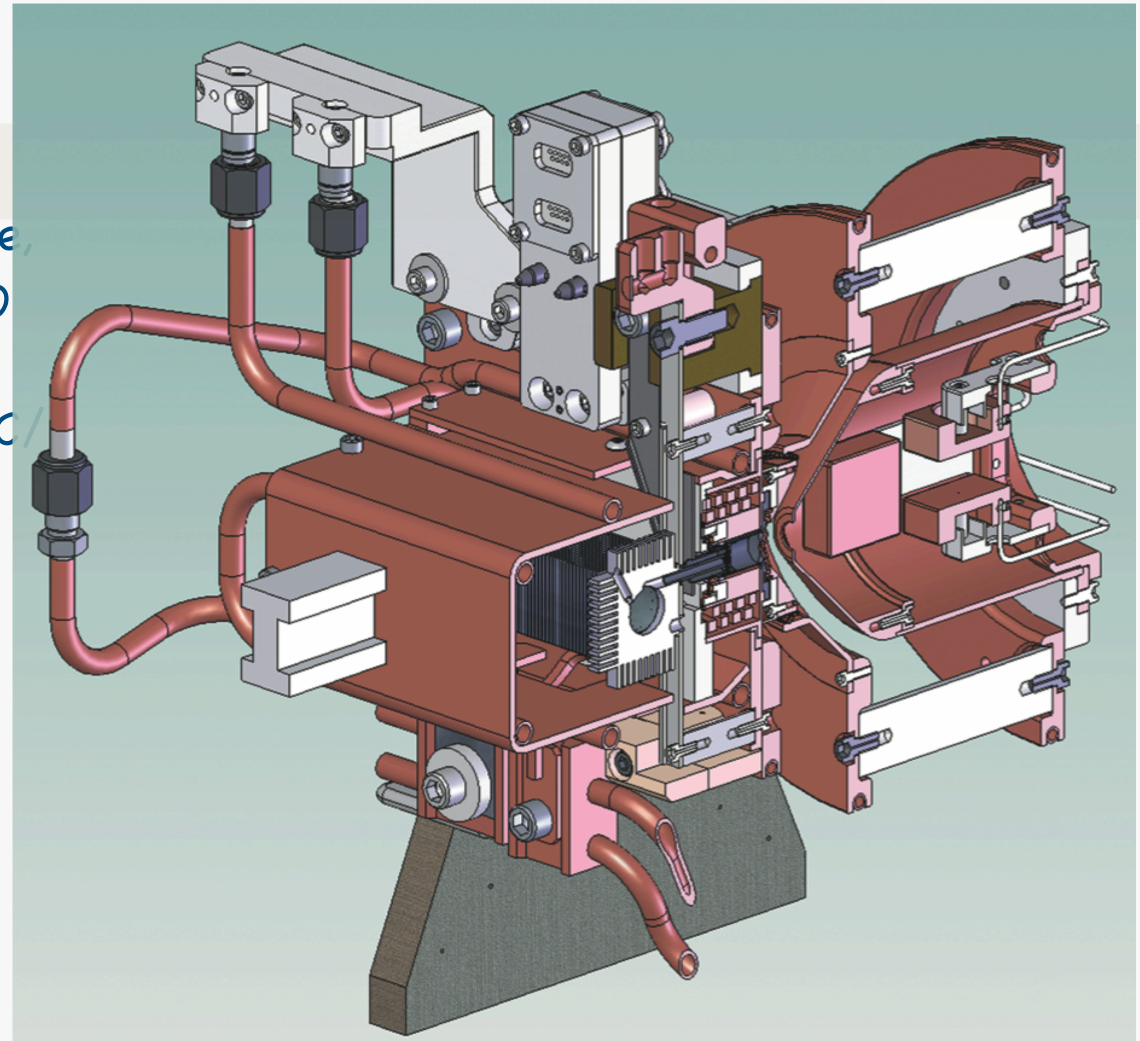

T RILIS isotopes on-line
status: 11/2012
tested TiSa laser schemes
status: 06/2011
TiSa network: Mainz, TRIUMF, ORNL, JYFL, GANIL, ISOLDE
Ti:Sa laser ionization scheme on paper (theory)
T RILIS development planned / ongoing
Jens Lassen
T RILIS status: 12/2012

hot plasma ion source FEBIAD

FEBIAD is a hot plasma ion source, used for TUDA $^{18}F(p,\alpha)^{15}O$

FEBIAD with a high power composite target se.g. SiC/gr, TiC/gr, ZrC/gr at 70 μA.

Developed plasma ion source operating with proton beam intensity up to 100 μA (50 kW beam power)



FEBIAD Ion Source, section view.

high performance ECR ion source

(i) Radiation resistant ECRIS for mono charged ions.

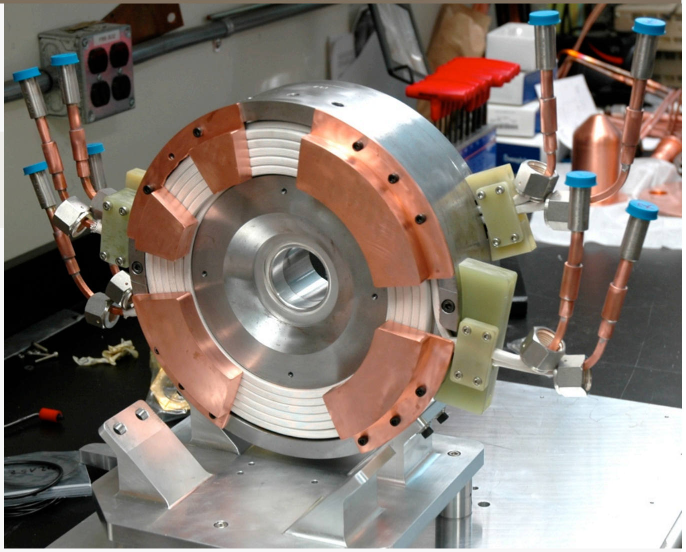
- No permanent magnets

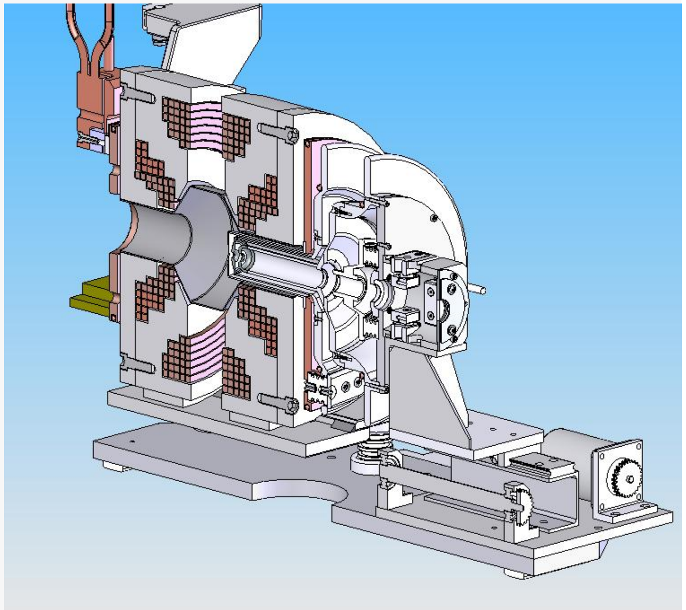
(ii) High level of confinement, using 4 coils arrangement

(iii) Tests were done to measure ionization efficiency

Element	I Eff %
F	72
Ne	48
Kr	48*
Xe	40*

- **higher charge state are produced also..**





Progress on UC2 targets in 2011

- Safety upgrades (target hall filtration system and various safety systems)
- CNSC license amendment (increasing max. p+ current from 2 μA / 1000 μAh to 10 μA / 5000 μAh)
- 2 UC_2 target runs at 2 μA (August 2011) and 10 μA (December 2011)

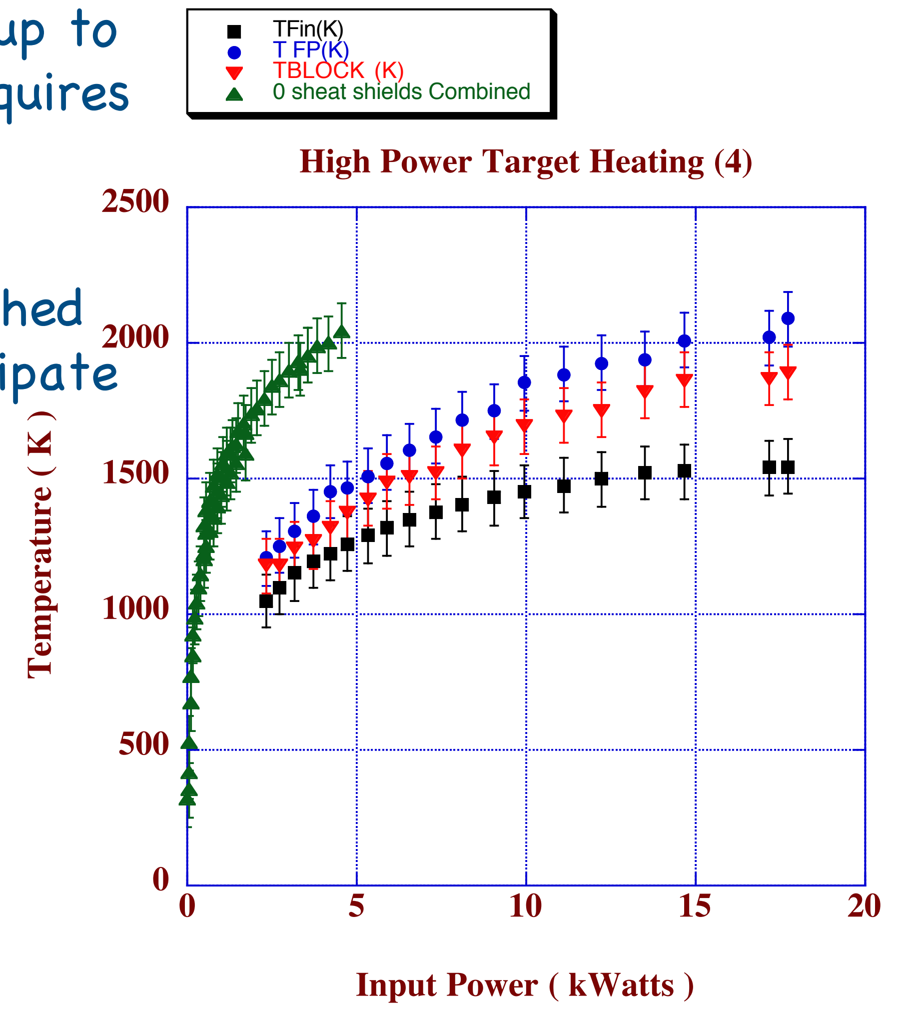
Extracted RIB:

Element	Ionization method	Element	Ionization method
Ac	Surface, laser	**Ca**	Surface
Ra	Surface	**K**	Surface
At	Laser	**Mg**	Laser
Fr	Surface	**Na**	Surface
Cs	Surface		
In	Surface		
Rb	Surface		

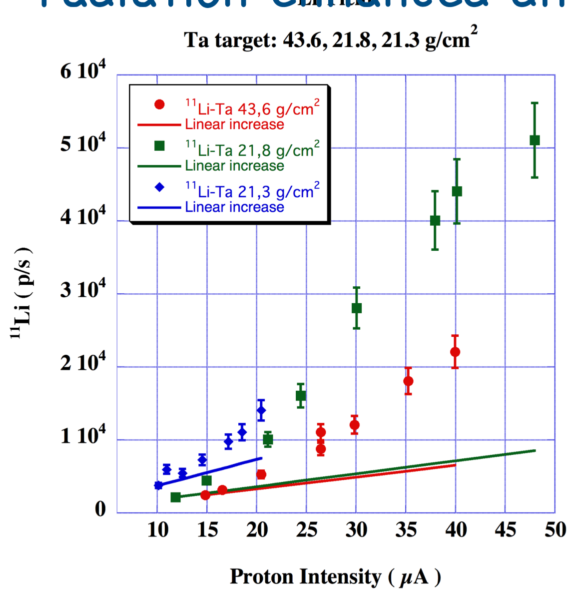
high power target

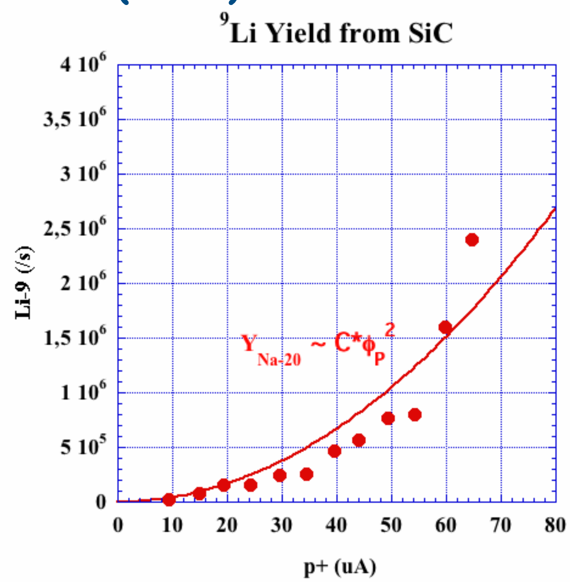
Low power target oven can dissipate up to 5 kW of beam deposition power -> requires ext. heating

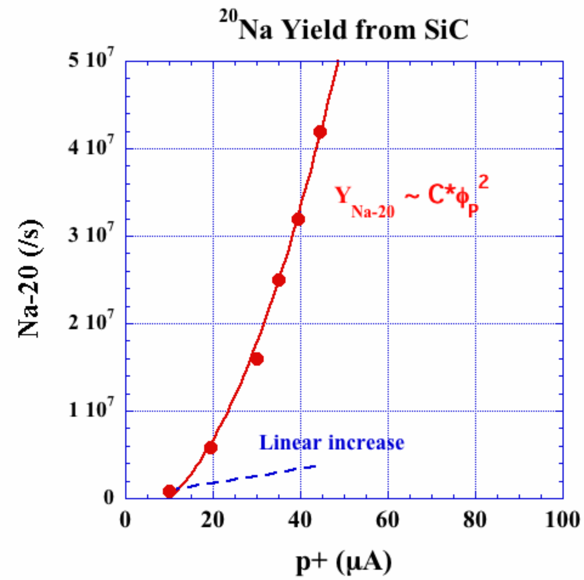
high power target oven has fins attached to the Ta tube and must actively dissipate up to 20 kW beam power



most striking result of operating at higher proton beam currents: radiation enhanced diffusion (RED).

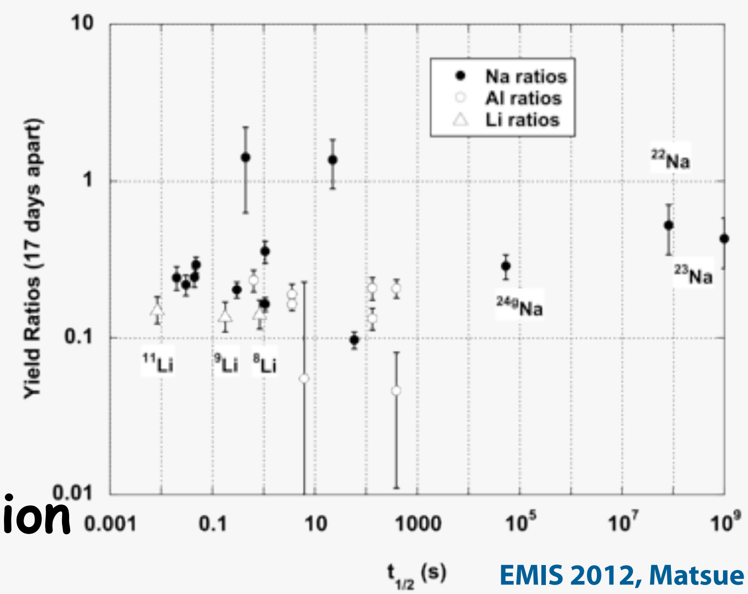






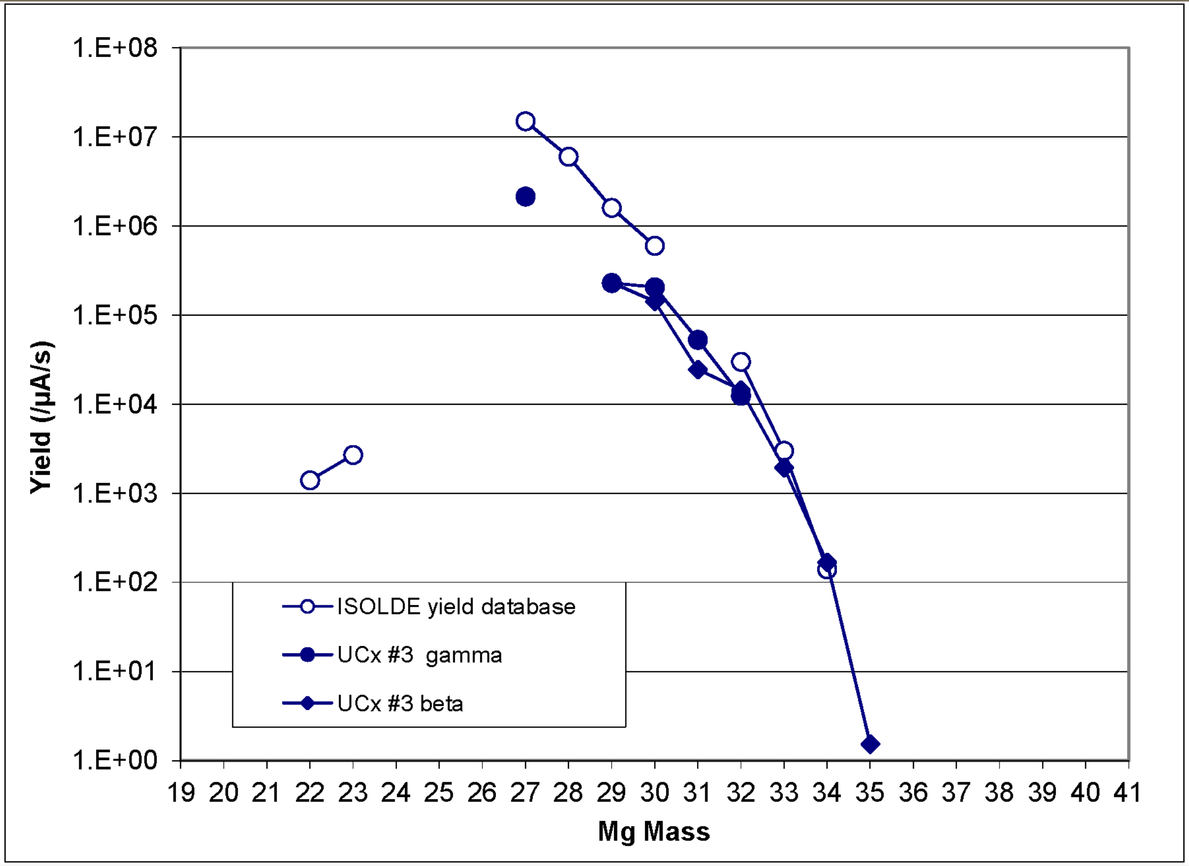
yield ratios

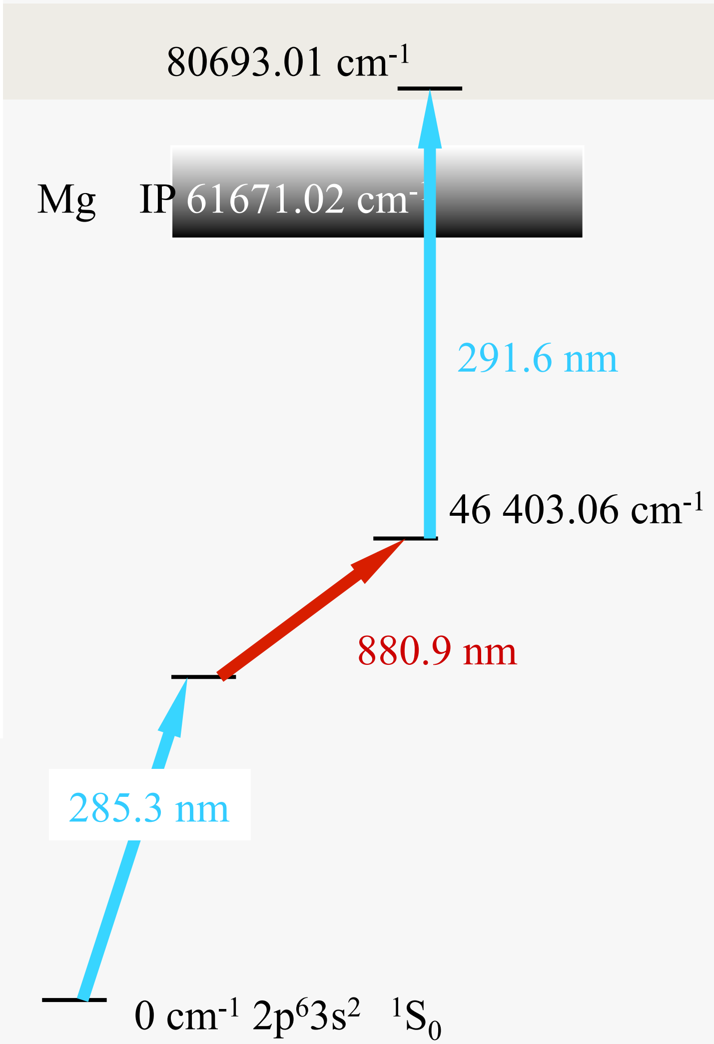
-> performance degradation



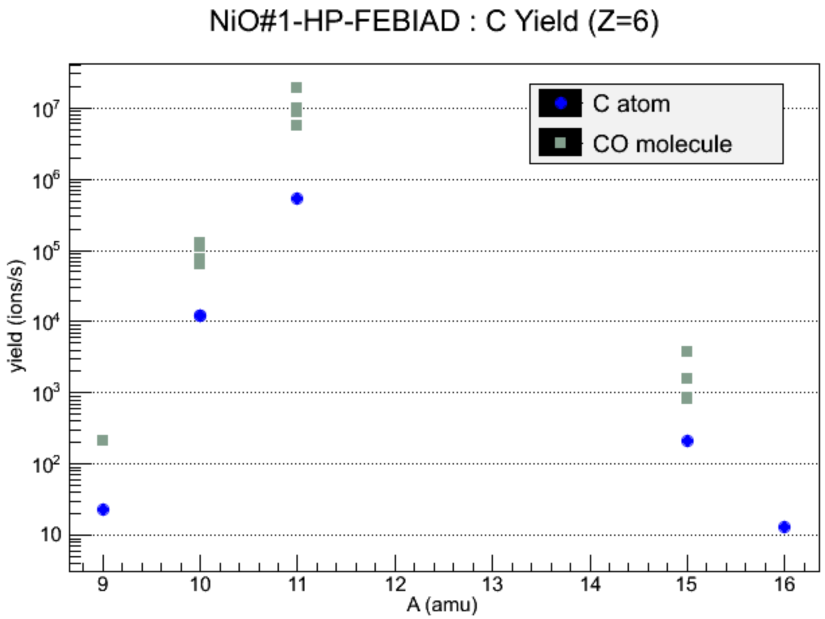
- Targets have to operate in high radiation dose environment making repair and maintenance extremely difficult and challenging.
- After been irradiated it is nearly impossible to have access to the target /ion source assembly for fine diagnostics.
  - Need high reliability
    - To guaranty beam time to users
    - RIB repeatability, to maximize beam time,
    - Minimize dose for repair and maintenance,

Neutron-rich Mg from UC_2 target #3

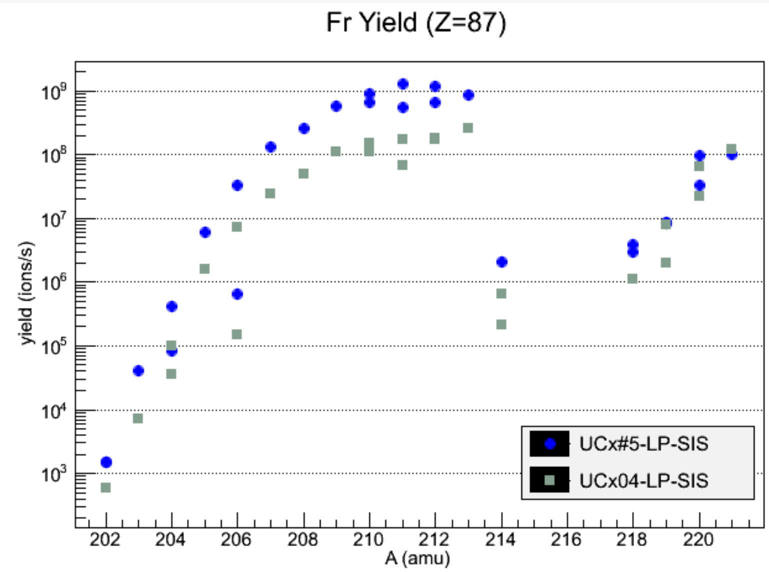




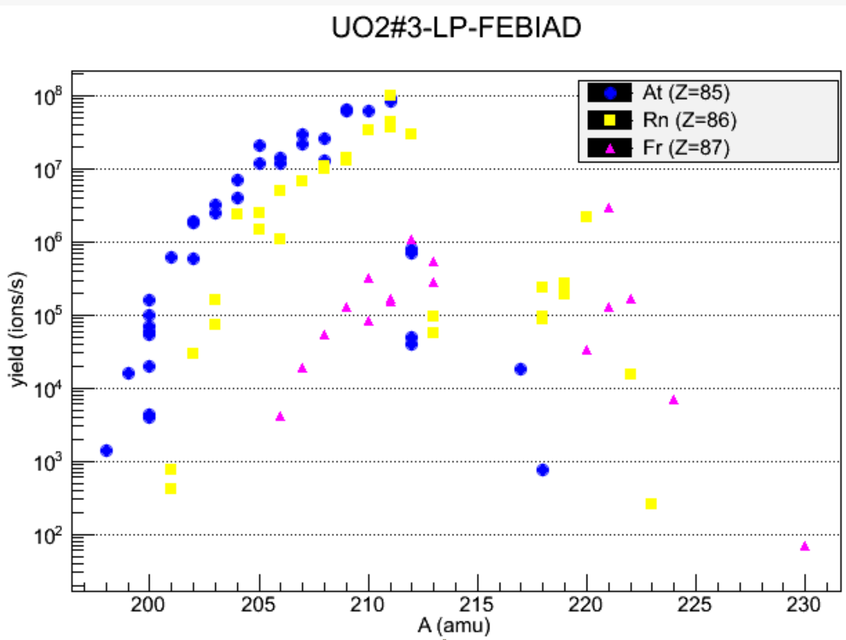
Resonant laser ionization provides a very pure beam, with a total ion yield ratio for *laser off/laser on* of $1.4 \cdot 10^{-4}$ @33amu.



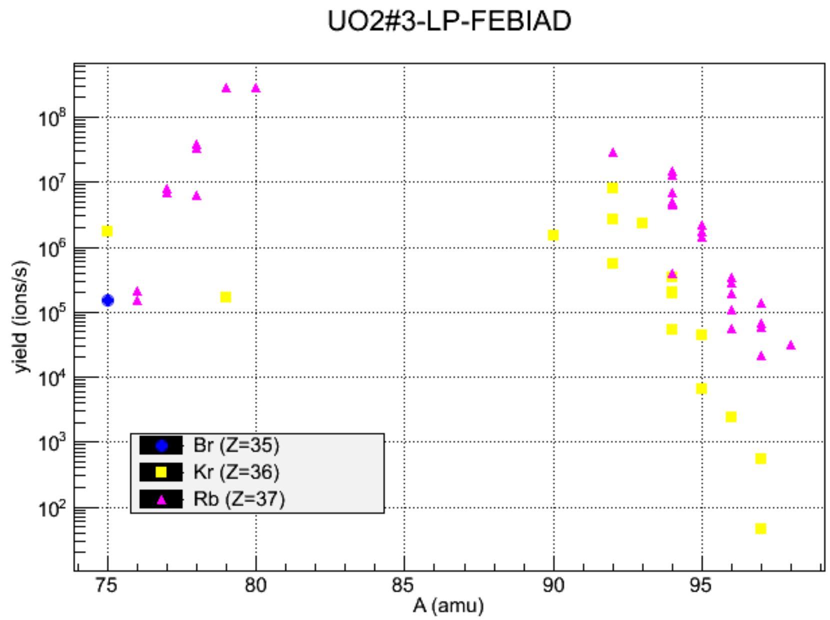
C and CO beams from a NiO-FEBIAD target



Further improvement of yields from UC_2 targets @ 10 μA

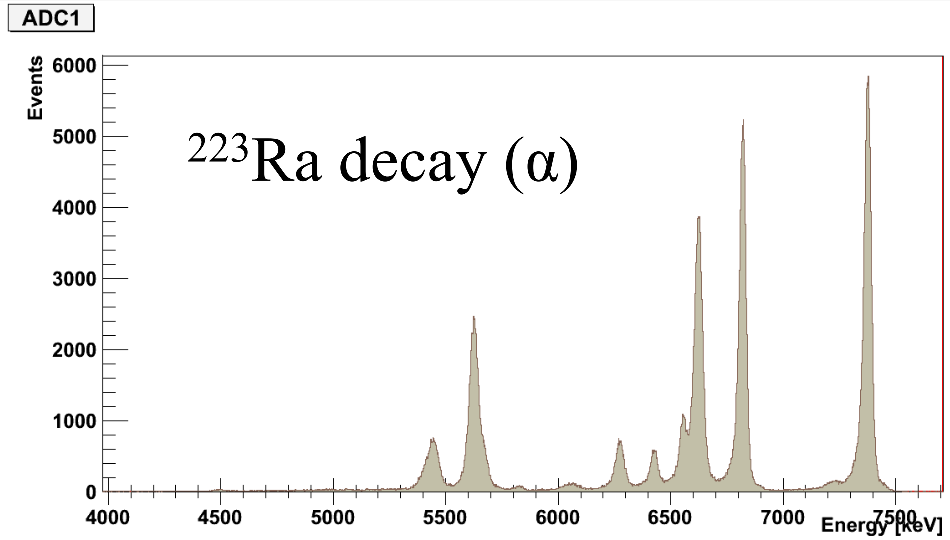


UO_2 #3 yields: Br, Kr, Rb and UC_x post irradiation



^{223}Ra	10^8/s
^{224}Ra	10^7/s
^{225}Ac	10^7/s

Post irradiation yields approx.
2 weeks after end of run

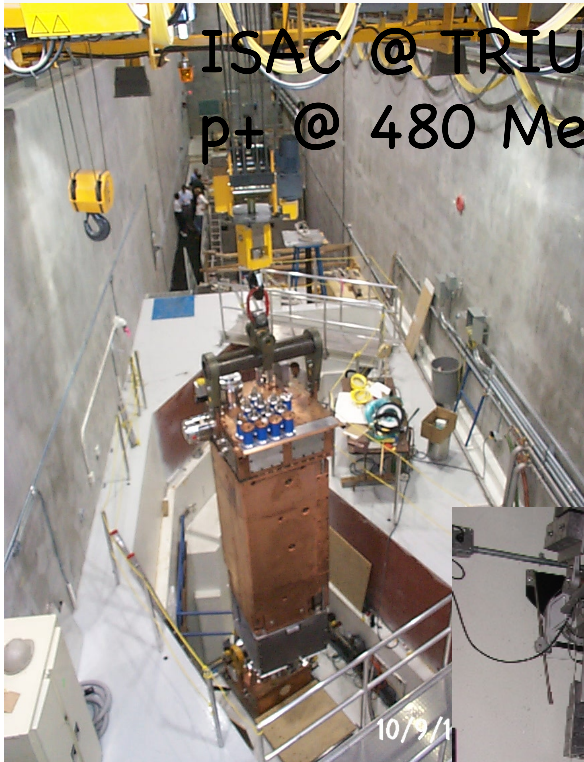


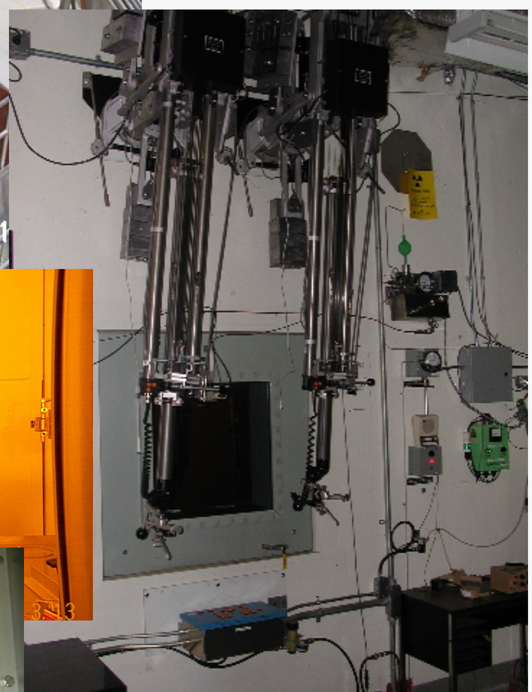
ISAC @ TRIUMF

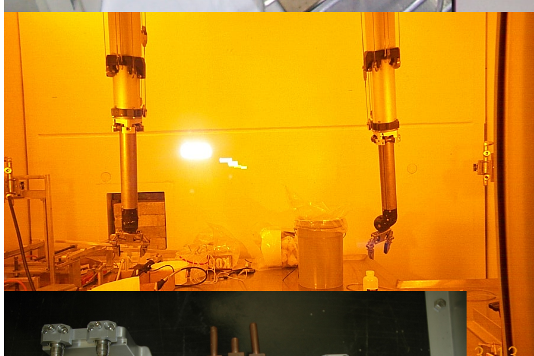
p+ @ 480 MeV Φ~ 100μA

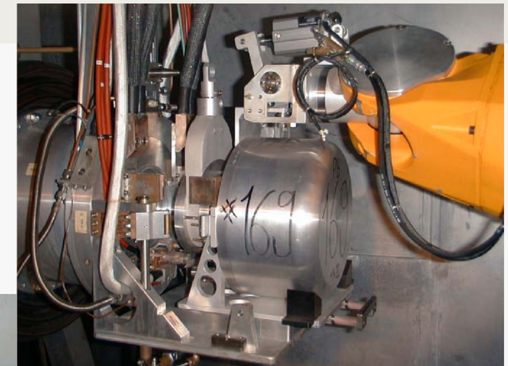
ISOLDE @ CERN

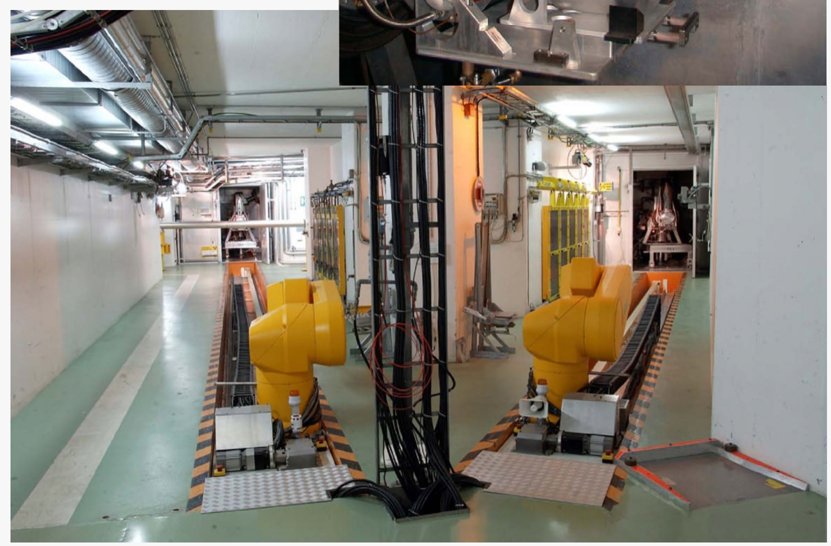
1.4 GeV Φ_{av} ~2μA









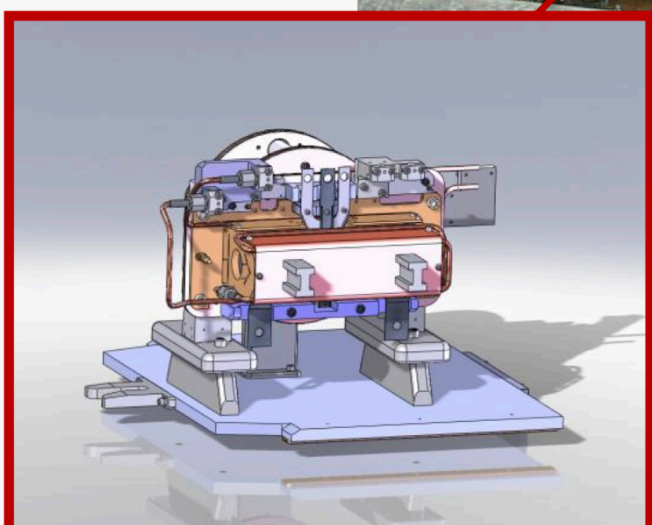


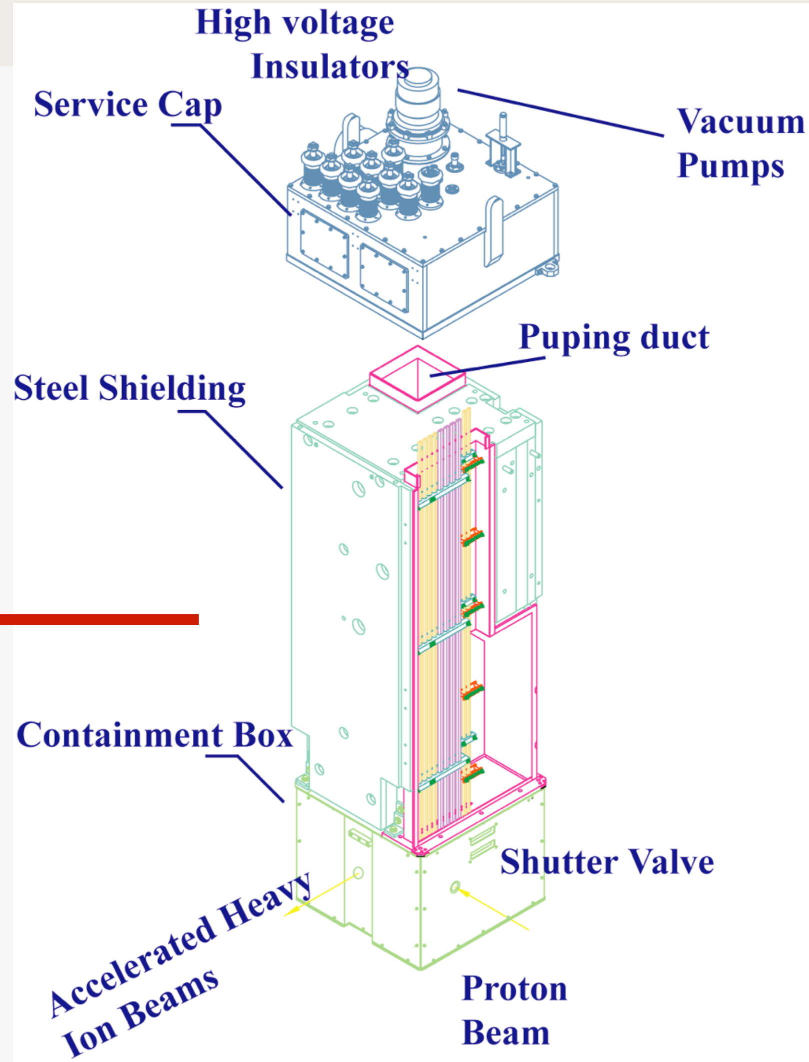
ISAC facility, technologies

(i) target module at bottom of shield plug

(ii) rad.sensitive components removed

(iii) manipulations in hot-cell





Failure mode & effect analysis FEMA -> relibability increase

Designs and processes have been analyzed to improve the Target/ion source reliability

FMEA is used in product development in manufacturing industries for example, where it helps to identify potential failure modes based on experience.

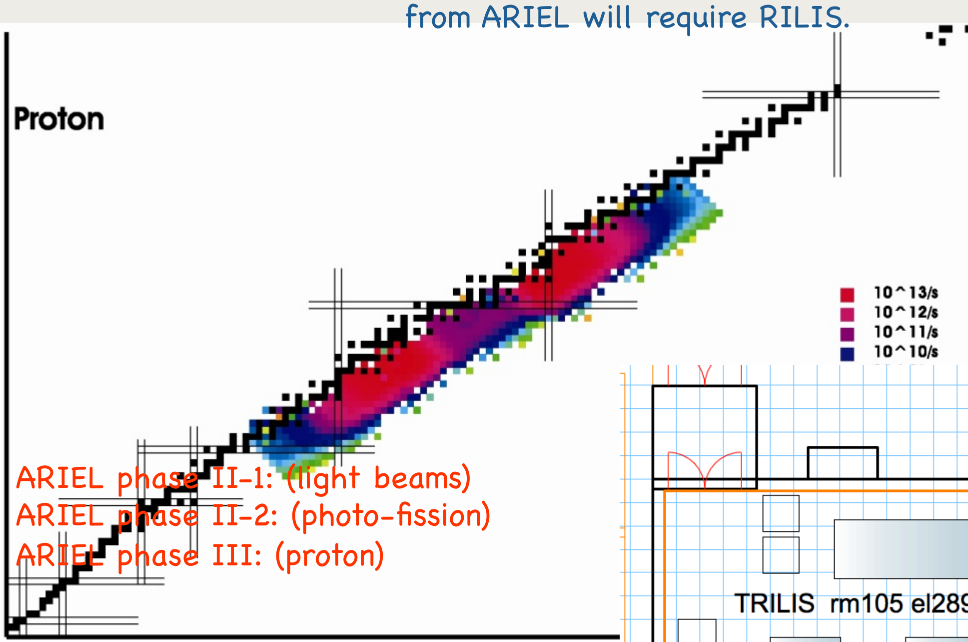
To help focusing on the critical failure mode(s) it is important to come up with some sort of rating of the risk.

Item/ function	Potential Failure Mode	Potential Effects of Failure	Potential Cause(s)	Severity (S)	Occurrence (O)	Current Control	Ease of Detection (D)	Risk Priority Number (RPN)	Critical Character Y/N	Recommended Actions, ECO number	Responsibility and Target Date for Completion	Action Taken

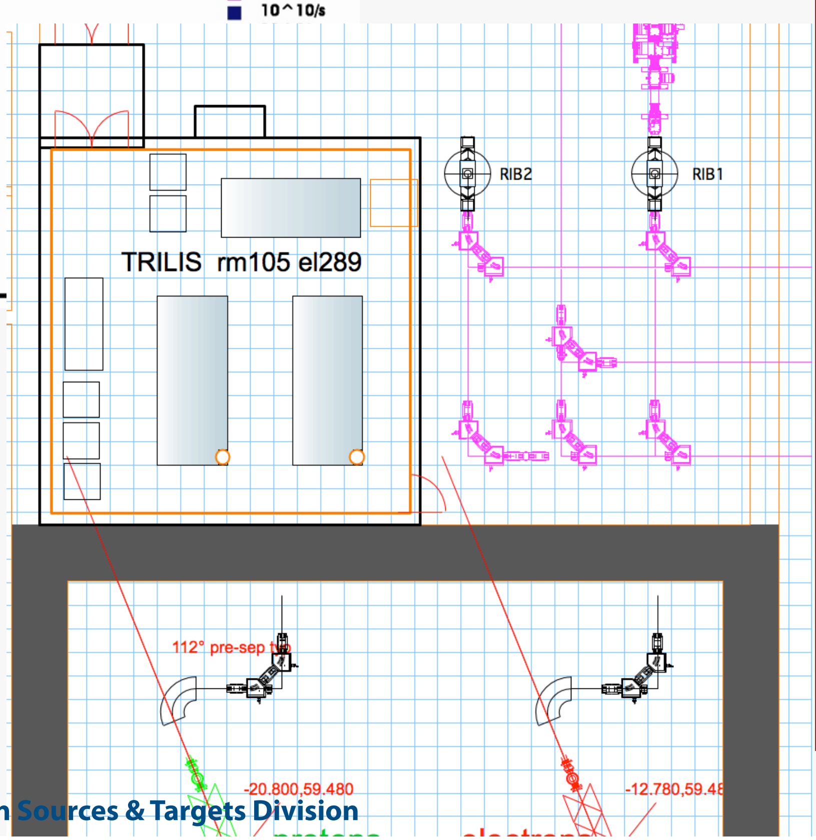
We have applied this analysis to prepare for next generation of RIB facility.

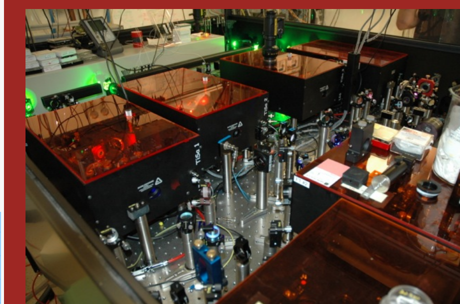
ALICE: ARIEL laser ion source

The unique ARIEL isotope production spectrum demands highest isobar selectivity. A resonant ionization laser ion source (RILIS) is uniquely in its ability for element selective ionization. It is expected that more than 50% of all rare isotope beams delivered from ARIEL will require RILIS.



ARIEL phase II-1: (light beams)
ARIEL phase II-2: (photo-fission)
ARIEL phase III: (proton)





future directions

new facilities using n and γ for U fission

- goal 10^{15} fissions/s

for reliable operation these targets have to be capable of sustaining power deposition in target, target chemistry & thermal conductivity.

⇒ development of composite UC_x and high power targets is critical for the success these facilities.

e.g. ARIEL photo-fission hinges on

high conductivity target material due to the high power deposited by the photons. (problem: e-e+ pair production).

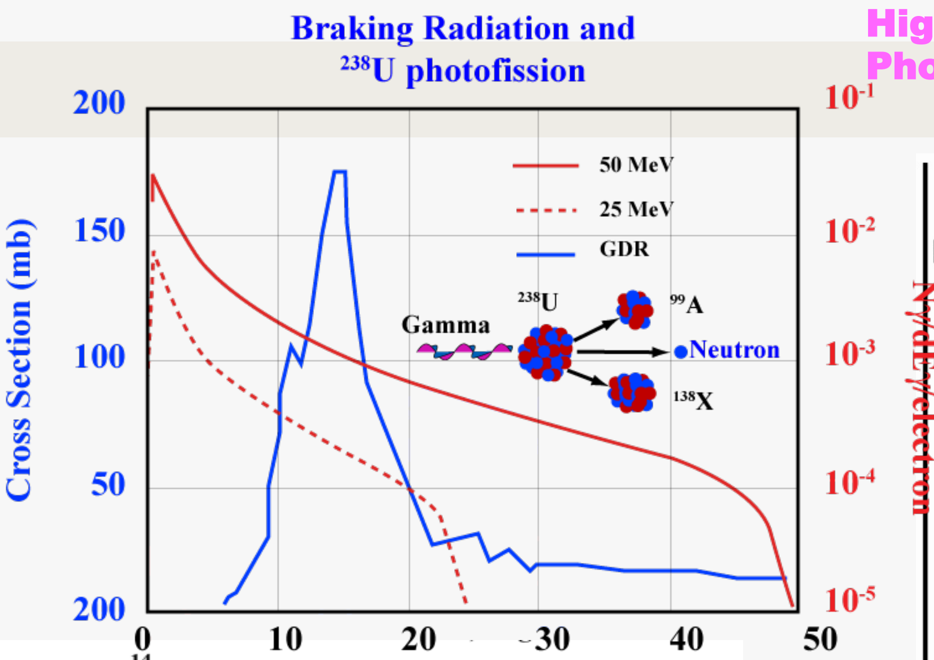
500 kW e^- => 75 kW power dissipation in the UC_x target.

Isobar suppression is imperative to enable successful experiments

=> Combination of techniques required

photo-fission characteristics

Photo-fission of 238U proposed by W.T. Diamond, CRL (1999)
Nucl. Phys. A 701 (2002) 87



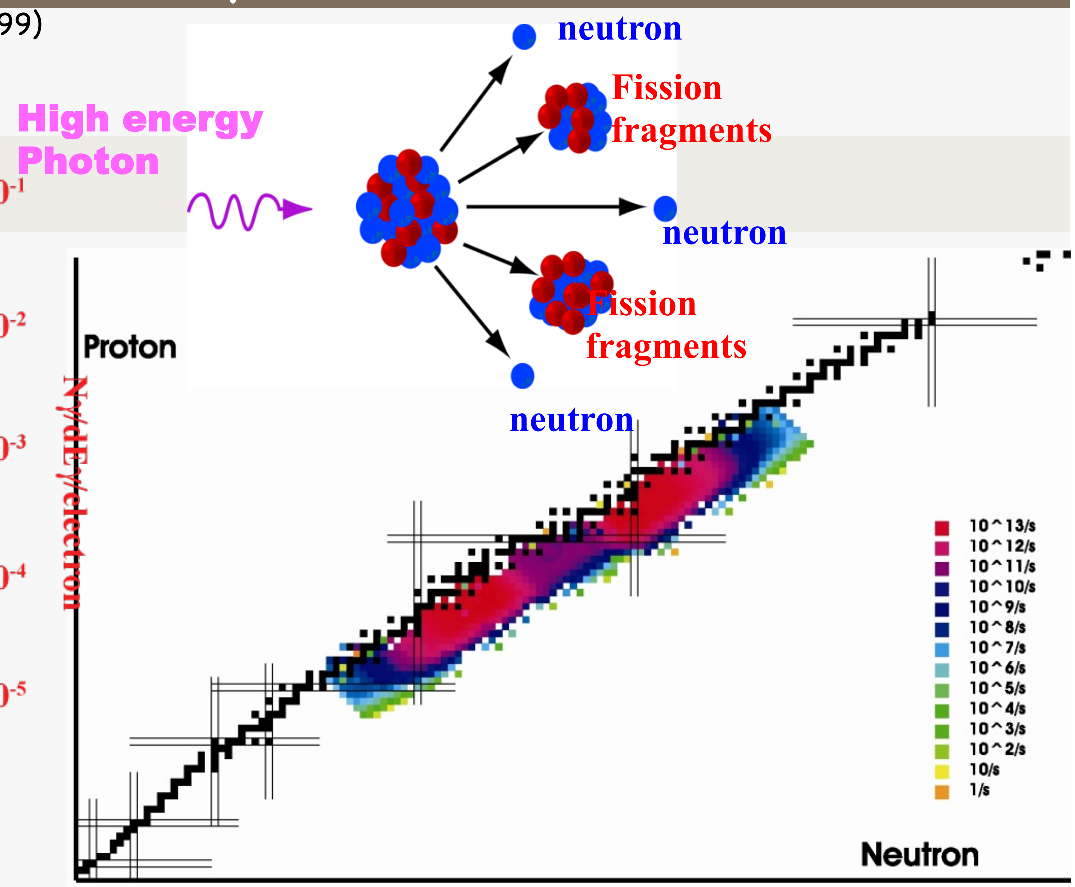
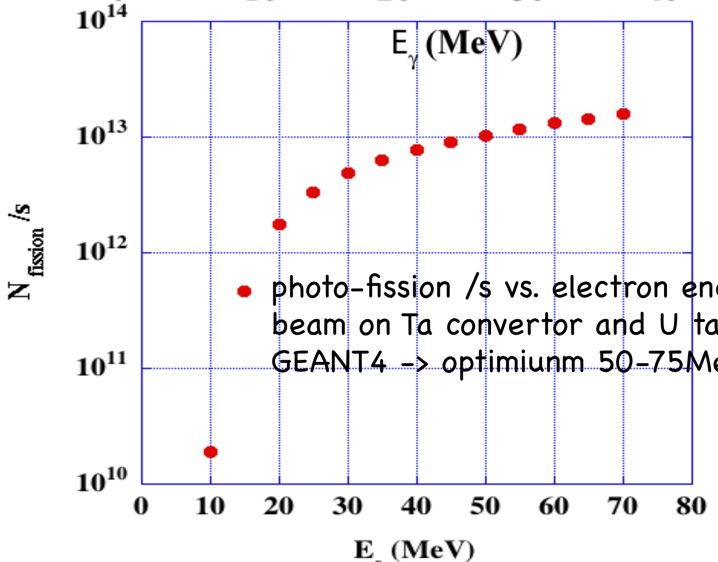
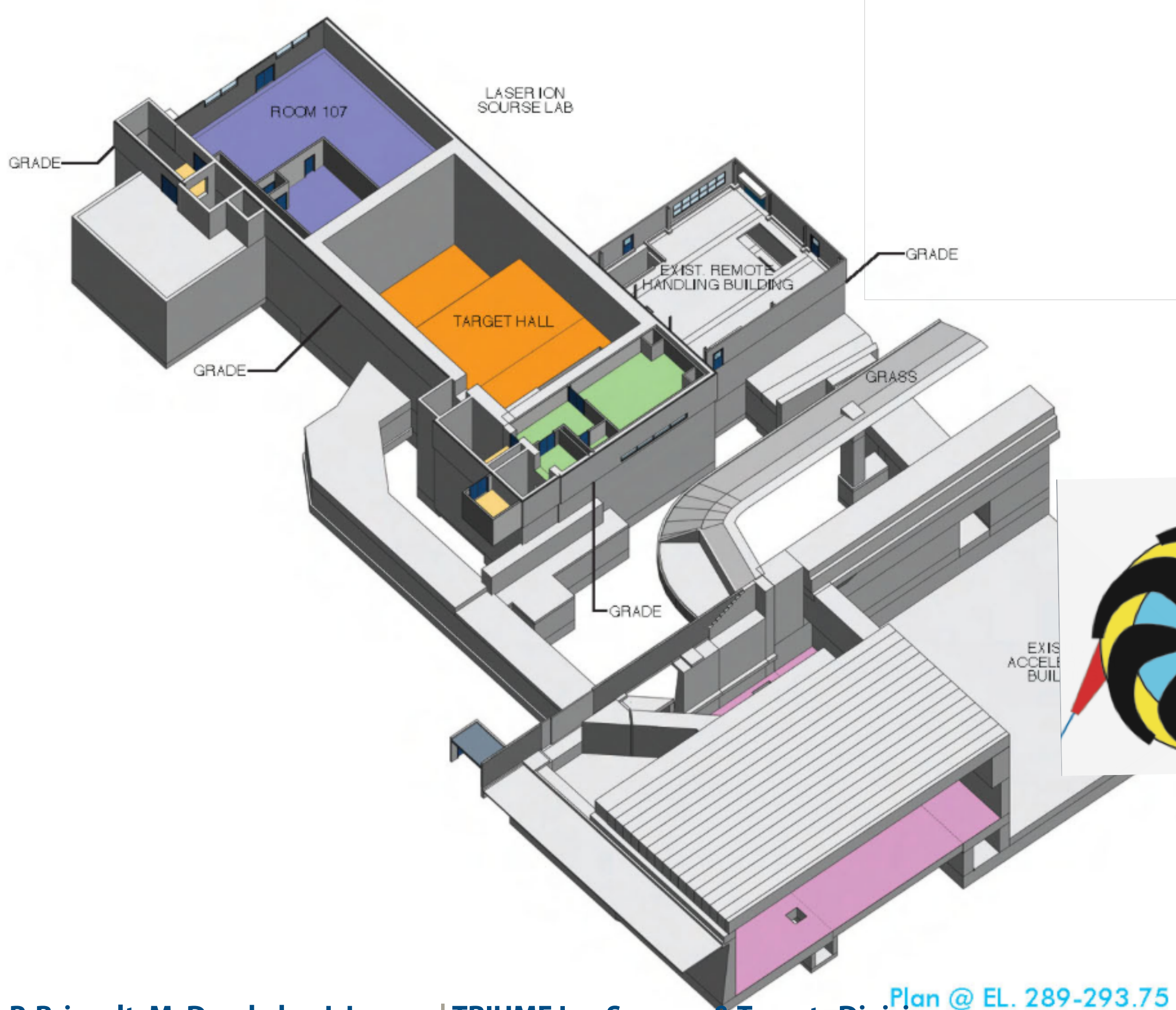


Photo-fission products distribution using 50 MeV 10 mA electrons on Hg convertor & UCx target



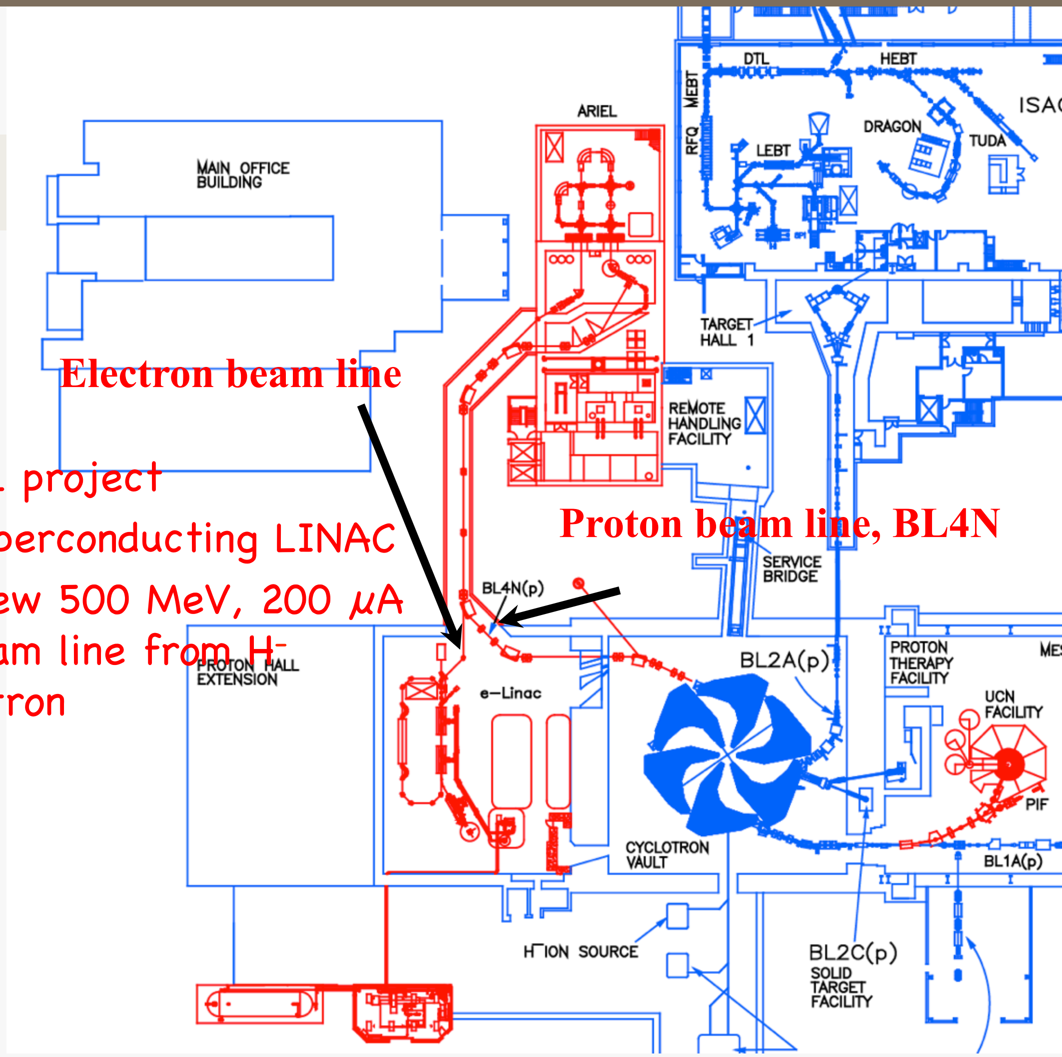
- photo-fission /s vs. electron energy for 100 kW e-beam on Ta convertor and U target. GEANT4 -> optimiunm 50-75MeV e- energy

Beam power (MW)	0.5
Duty Factor	100%
Average current (mA)	10
Kinetic energy (MeV)	50



ARIEL construction on schedule complete 3/2013

more RIB to users
multiplexing



ARIEL project

e^- superconducting LINAC

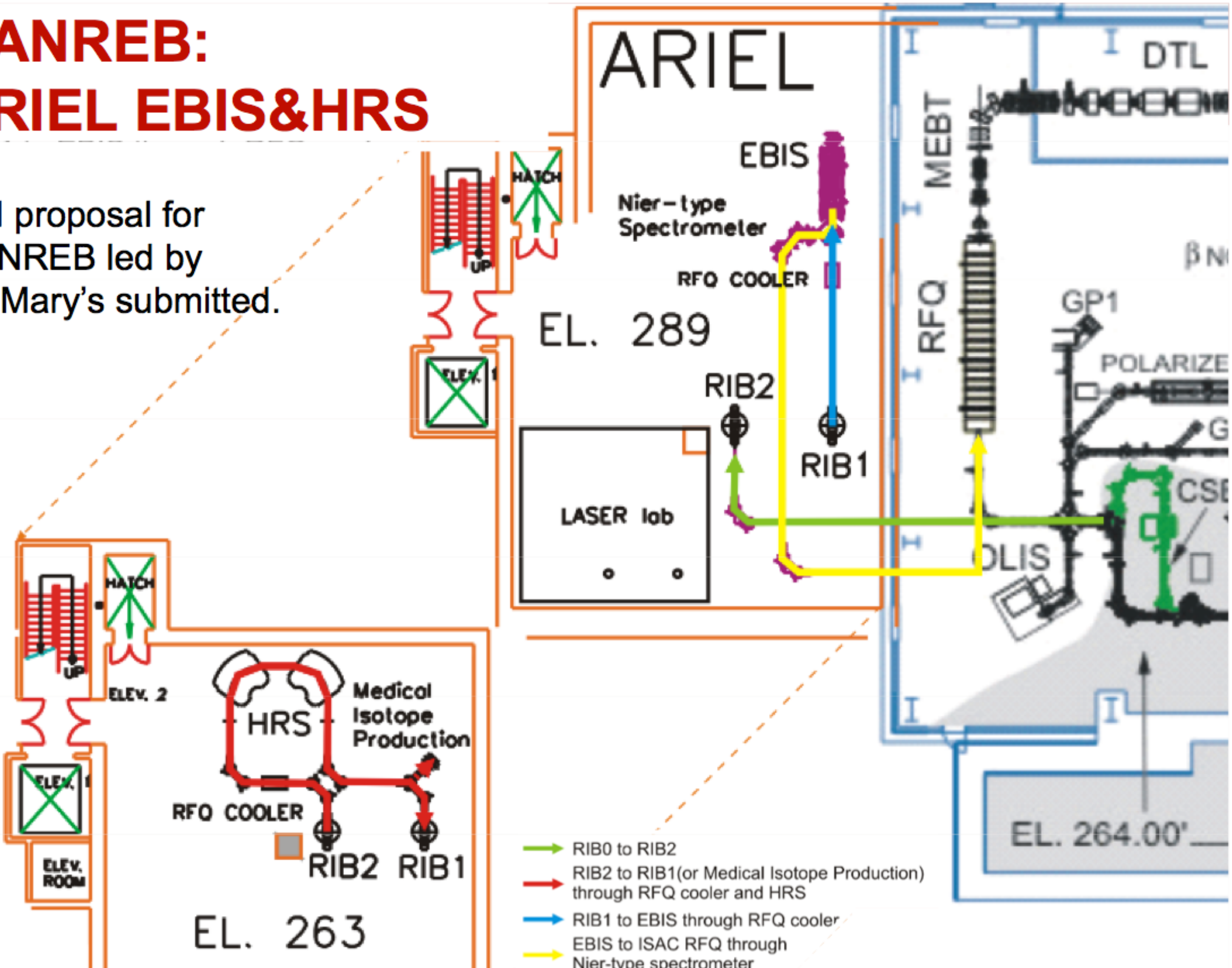
& new 500 MeV, 200 μA

p^+ beam line from H^- cyclotron

ISAC RI beam Facility is one user only. Back log is important

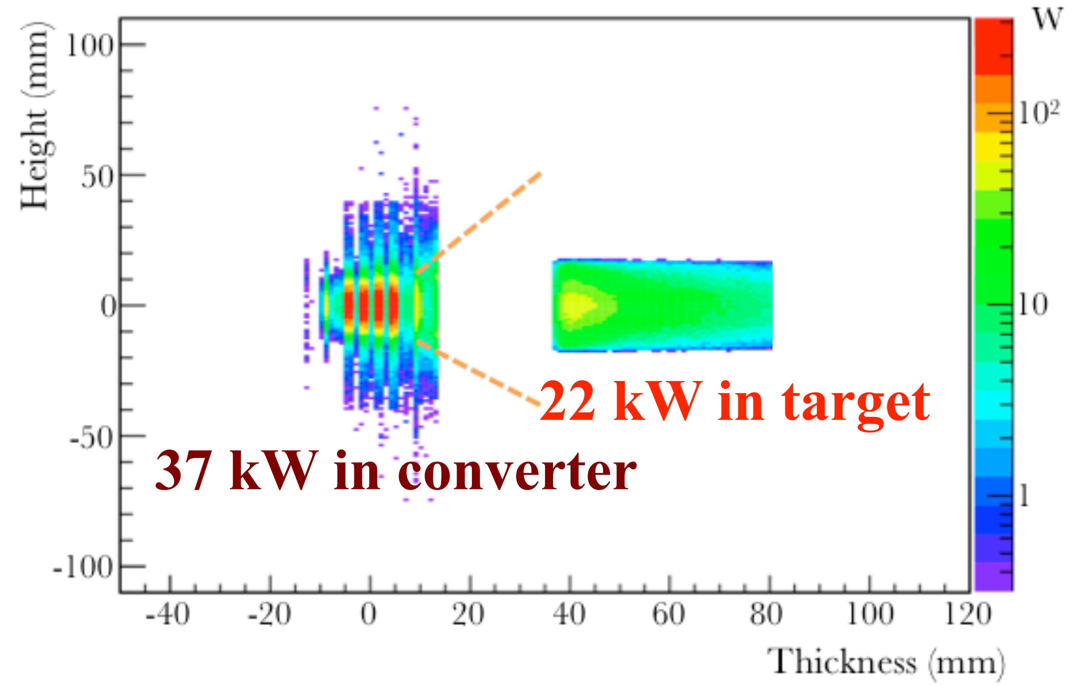
CANREB: ARIEL EBIS&HRS

CFI proposal for CANREB led by St. Mary's submitted.



100 kW converter

GEANT4 simulation shows that 96% of the γ are within a 10° cone



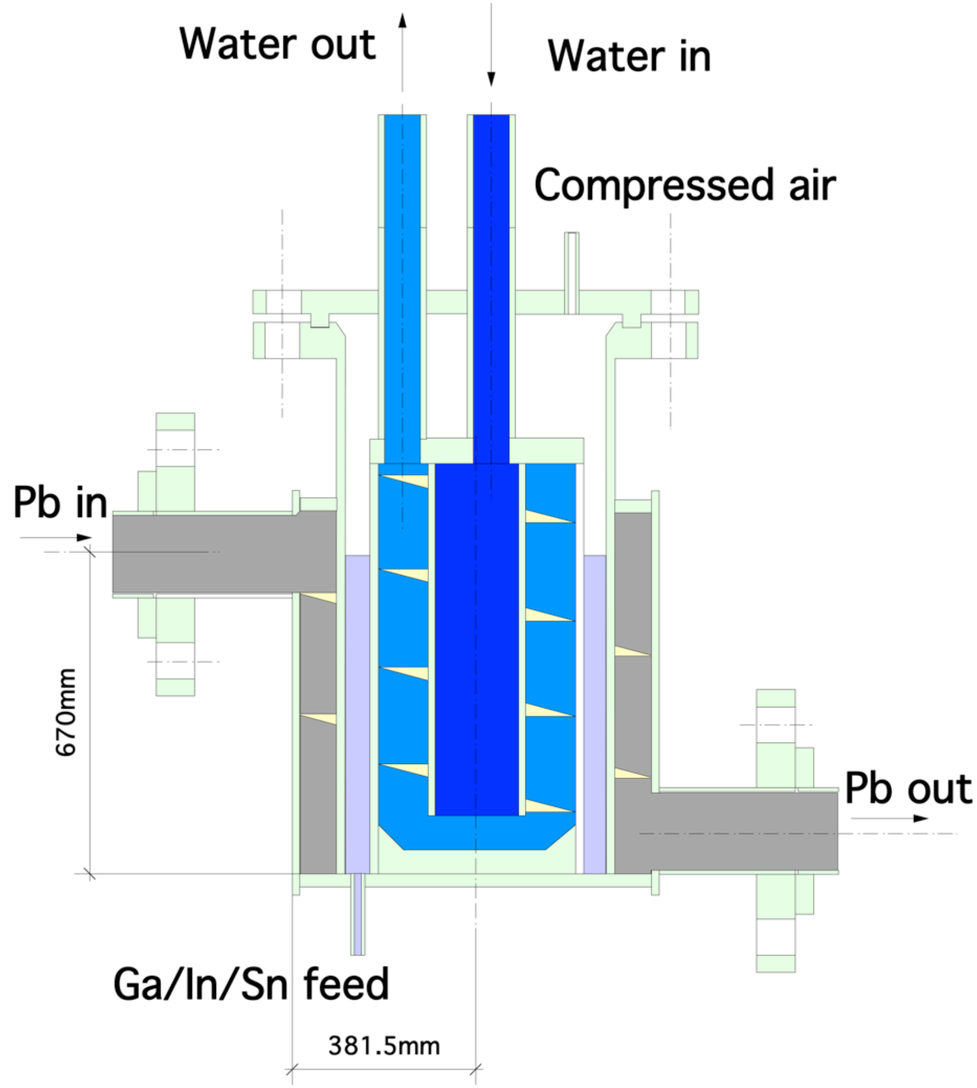
Power distribution for a 100 kW beam onto a Ta converter and UC_2 target

500 kW converter

For beam power above 150 kW apply the static target solution for a converter.

Options for a ½ MW converter:

Water-cooled rotating wheel:
    Liquid metal converter
Power distribution:
    74 kW in converter, 75 kW in targ



ISOL targets future directions

- The is a long list of new ISOL proposals and projects under way with the goal to increase the RIB intensity:
  - SPIRAL-II, ARIEL, KoRIA, CARIF, EURISOL, ANURIB ...
- All these projects or proposals utilize a much higher beam power or power deposition in the target material
  - either from neutrons or high energy gammas
- Target stations and target/ion source assemblies have to be designed in consequence of this new paradigm.

caveats:

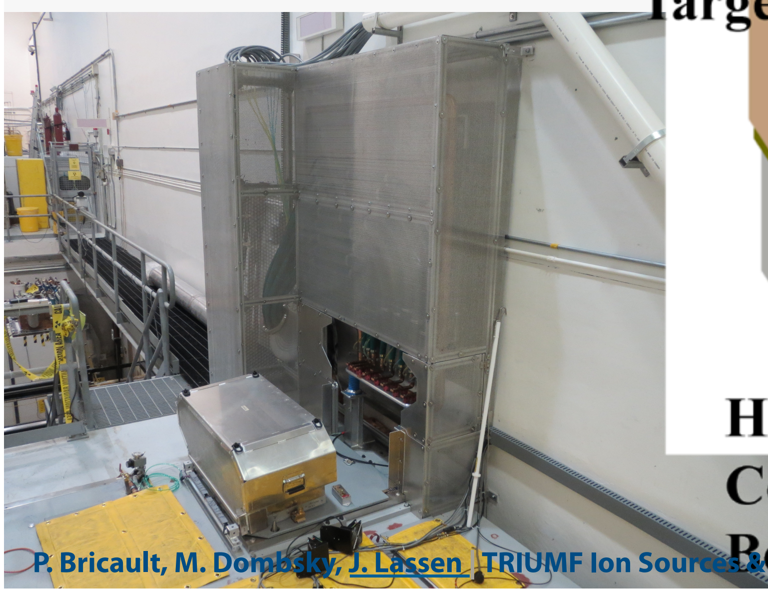
(i) it may be more cost effective to improve target release parameters and isobar suppression over brute force driver power increase

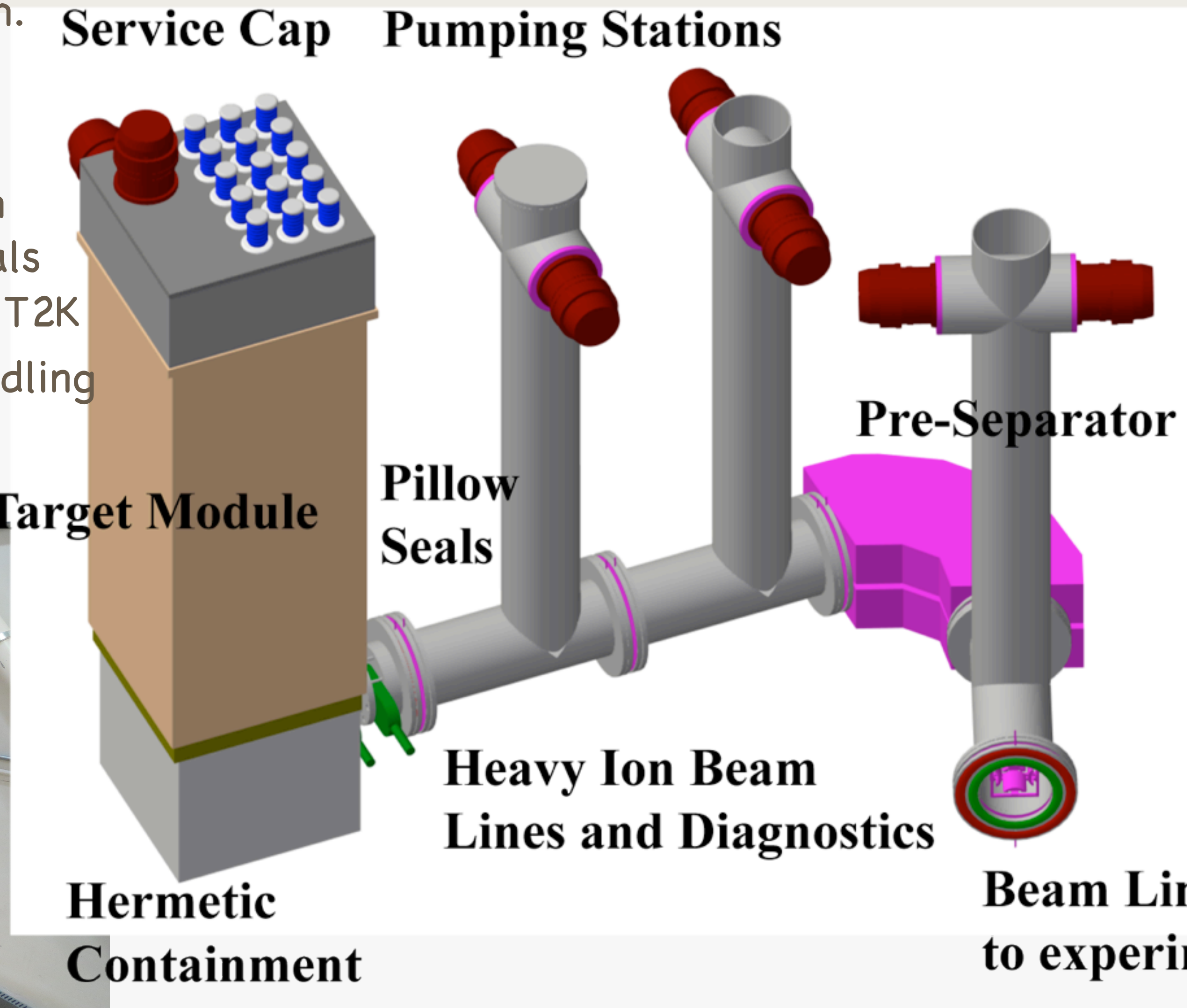
(ii) Licensing requirements will have to be observed -> nuclear inventories matter

ARIEL/TRIUMF target station concept

Uses Target Module similar as for ISAC – evolution not revolution:

- Sealed containment box.
- Simplified vacuum system.
- Better vacuum
- Quick disconnect vacuum envelope using pillow seals technique developed for T2K
- Designed for remote handling access.





critical technologies for higher ISOL RIB intensity

(i) High power tolerant targets & ion sources

- Refractory foils target, Ta, Nb ... operate at 100 μA, corresponding to 50 kW proton beam power
- Composite target have high thermal conductivity
  - Carbide targets, SiC, TiC, ZrC, UC on Graphite foil are operating in the range of 70 to 80 μA, 500MeV p+
  - Oxide targets, NiO, Al_2O_3 on Nb or Ta foil run at 20 to 35 μA p+

(ii) Target container capable to dissipate the beam power from target material -> container -> heat-shield -> cooling system.

(iii) Beam trip limitation T_{trip}<5sec, as beam trips temperature cycle.

Critical Technologies for Higher ISOL RIB Intensity

(iv) Ion Source: capable of operating efficiently in a wide pressure range

(v) Bridge the gap between species available with ISOL method.

Force non volatile species into more volatile molecular form, e.g.

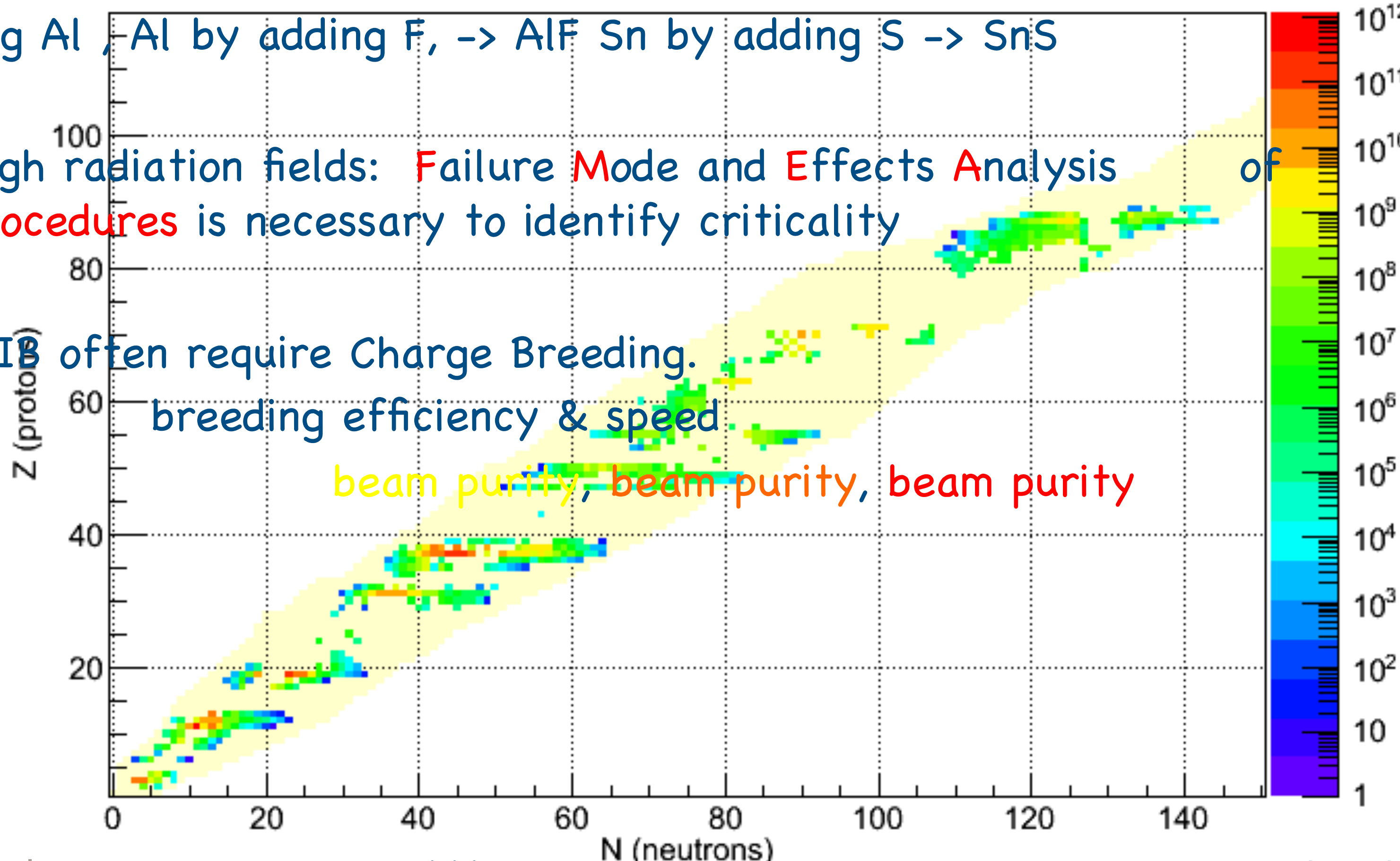
F by adding Al , Al by adding F, -> AlF Sn by adding S -> SnS

(vi) Reliability in high radiation fields: Failure Mode and Effects Analysis of system design & procedures is necessary to identify criticality

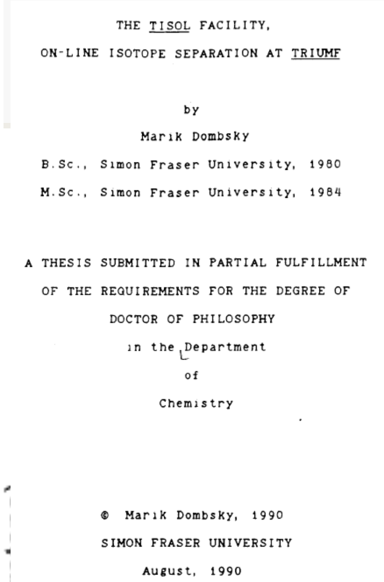
(vii) accelerated RIB often require Charge Breeding.

breeding efficiency & speed

beam purity, beam purity, beam purity



Marik Dombsky ISAC target chemist, ret.


THE TISOL FACILITY,
ON-LINE ISOTOPE SEPARATION AT TRIUMF

by

Marik Dombsky

B.Sc., Simon Fraser University, 1980

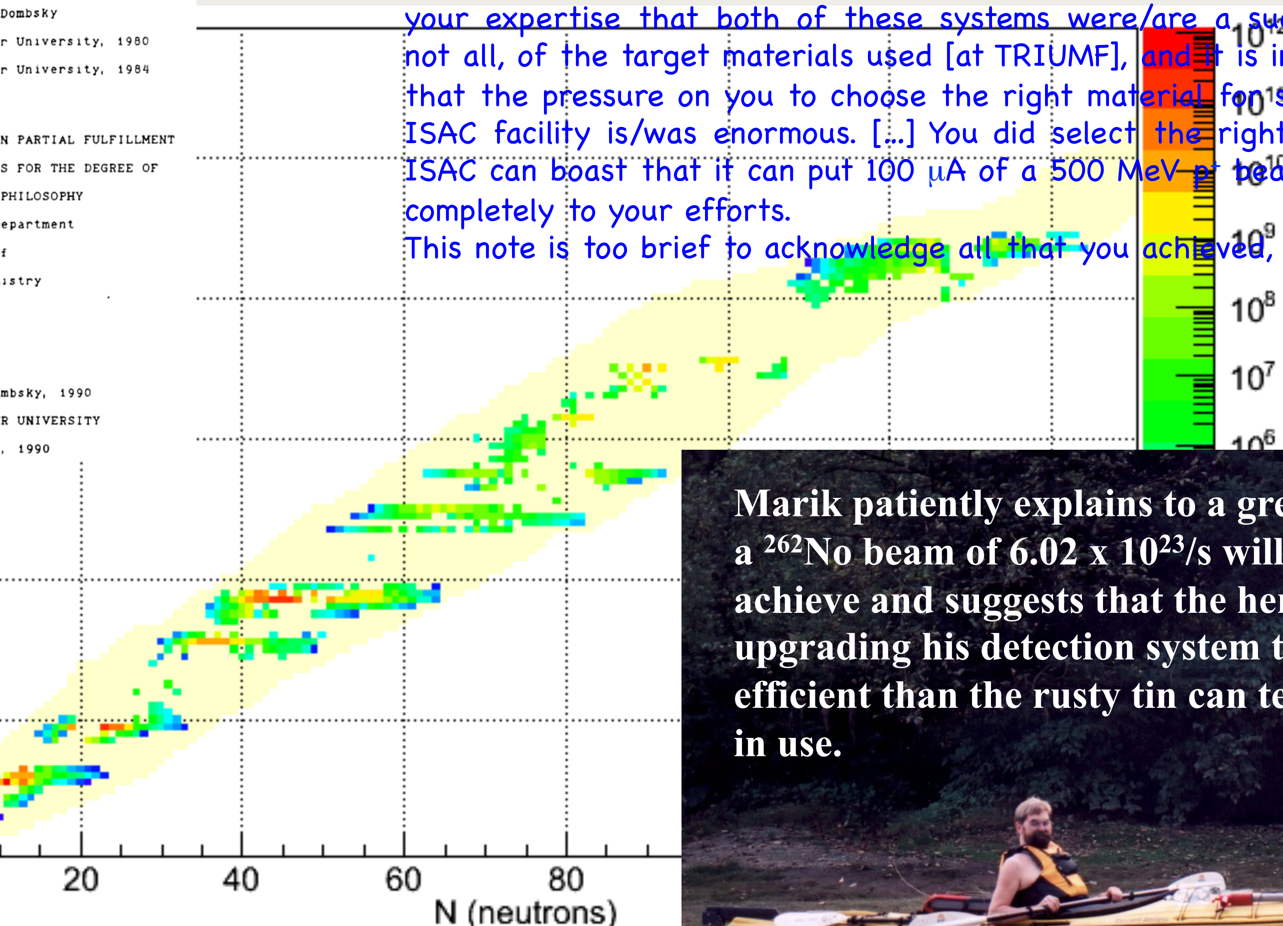
M.Sc., Simon Fraser University, 1984

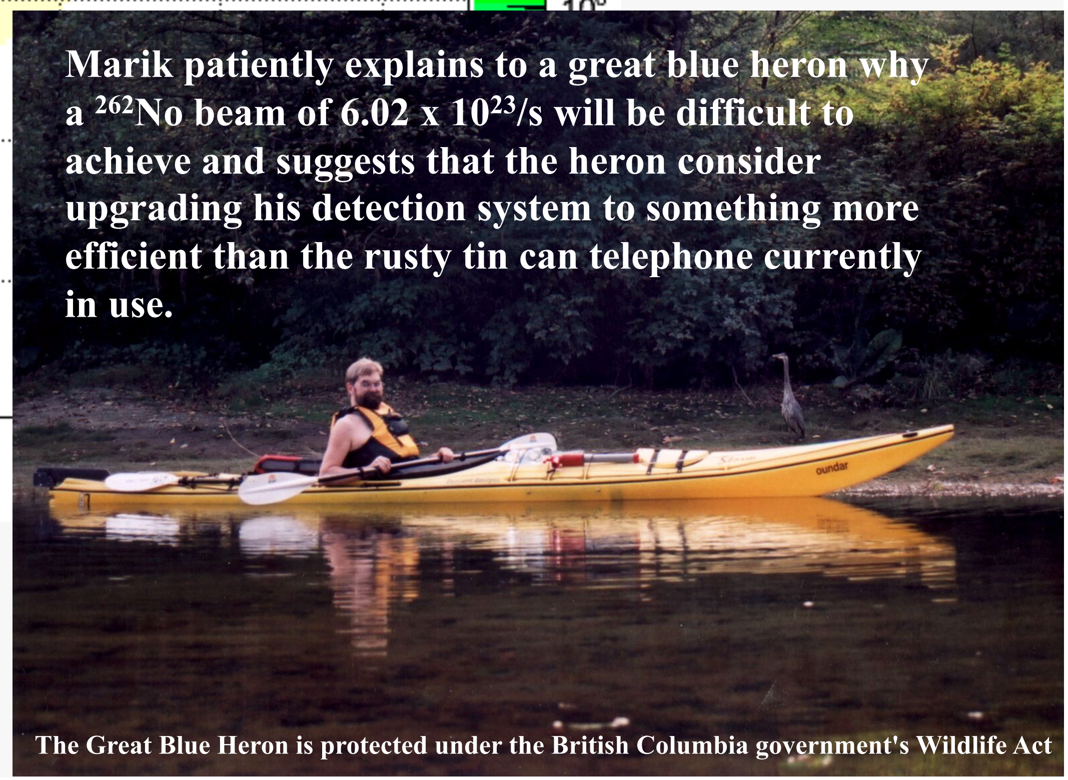
A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
in the Department
of
Chemistry

© Marik Dombsky, 1990
SIMON FRASER UNIVERSITY
August, 1990

… to acknowledge publicly the excellent work you have performed over the years for TRIUMF in many capacities. […] Both TISOL and ISAC are ISOL devices and the key component of an ISOL is the target and ion source front end. It was due to you and your expertise that both of these systems were/are a success. You developed many, if not all, of the target materials used [at TRIUMF], and it is important for all to appreciate that the pressure on you to choose the right material for such a complex system as the ISAC facility is/was enormous. […] You did select the right material generally, and now ISAC can boast that it can put 100 μA of a 500 MeV p⁺ beam onto its targets. This is due completely to your efforts.
This note is too brief to acknowledge all that you achieved, but again…THANKS..

By John D'Auria





Marik patiently explains to a great blue heron why a ^{262}No beam of 6.02 x 10^{23}/s will be difficult to achieve and suggests that the heron consider upgrading his detection system to something more efficient than the rusty tin can telephone currently in use.

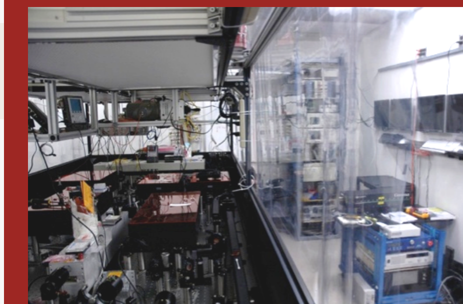
The Great Blue Heron is protected under the British Columbia government's Wildlife Act

TRIUMF IST group:
F. Ames, P. Bricault, M. Dombsky, J. Lassen, P. Levy, G. Minor, B Moss, J. Wong, R. Mahaharaj, A. Laxdal, D. Jackson, M. della Valle, F. Labrecque

New(er) Generation of ISOL Target Station for Intense RIB

Radioactive Isotope Beam Physics
High intensity, clean, rare isotope beams – the continuous quest -

Pierre Bricault, Friedhelm Ames, Jens Lassen, Marik Dombsky
| TRIUMF Targets & Ion Sources Dept.



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

Canada | British Columbia | Canada Foundation for Innovation / Fondation canadienne pour l'innovation | CIHR IRSC | NRC CNRC | NSERC CRSNG | Western Economic Diversification Canada / Diversification de l'économie de l'Ouest Canada | Natural Resources Canada / Ressources naturelles Canada

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