TRIUMF

Pushing the Frontier of Accelerator Target Materials at TRIUMF

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Discovery, accelerated

Discovery, accelerated

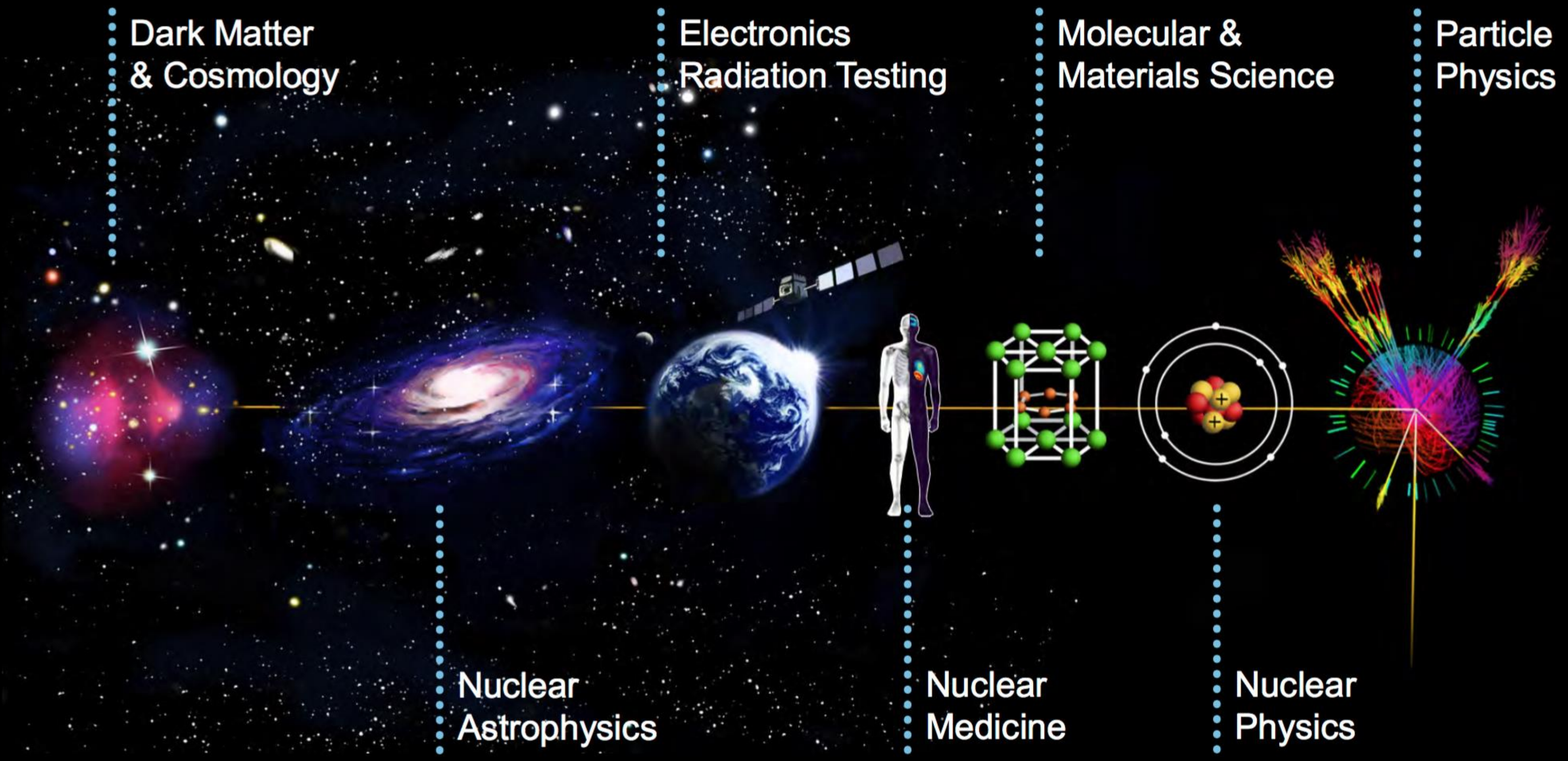

TRIUMF

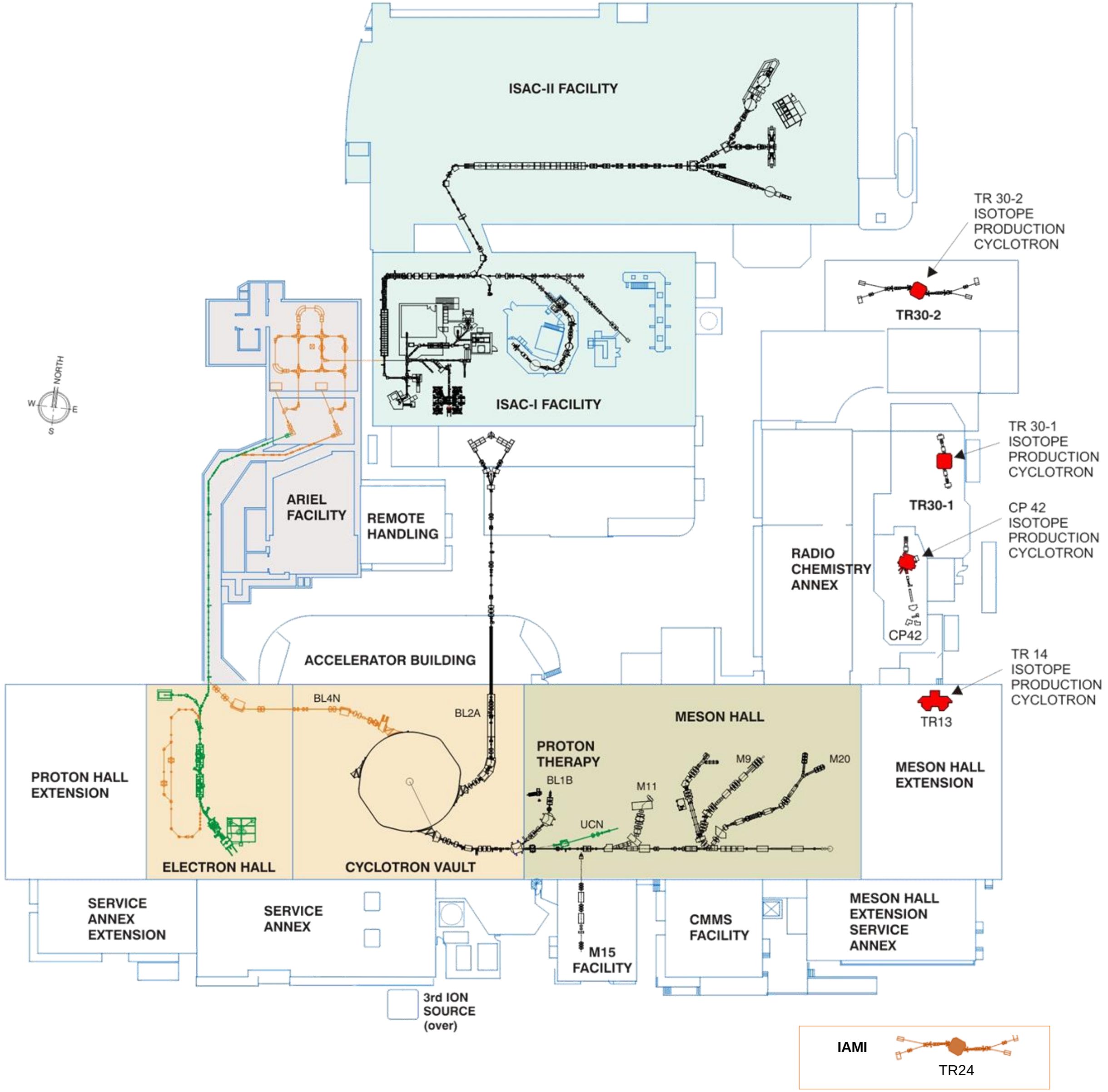
Canada's Particle Accelerator Centre

400 staff
200 students
post-doctoral
researchers

1100 scientific
visitors per year

TRIUMF’s Research Program – Radioisotopes for Science



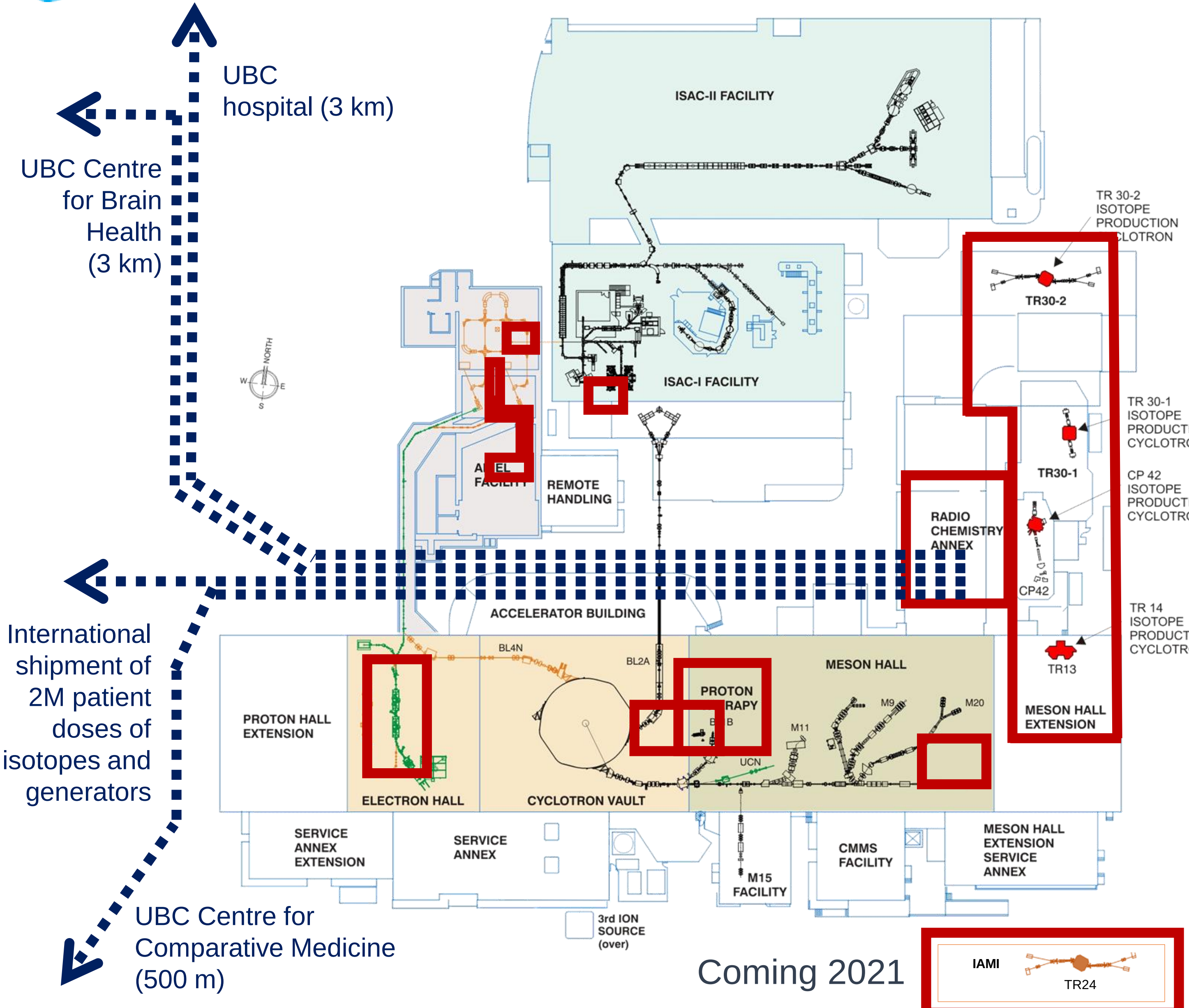


TRIUMF accelerators

- 520 MeV, 200 kW cyclotron
- 30 MeV, 100 kW e-linac
- Cyclotrons: TR30-1, TR30-2, TR14, TR24, CP42
- Heavy ion accelerators

TRIUMF

TRIUMF's Medical Isotope Factory



Five H⁻ medical cyclotrons

- TR30-1, TR30-2, CP42, (solid, liquid and gas targets)
  - Operated by ATG for BWXT
  - 2M doses annually
- TR13 (solid, liquid and gas targets)
- TR24 (gas, solid, liquid targets)

H^+ from 90-500 MeV, 300 µA cyclotron

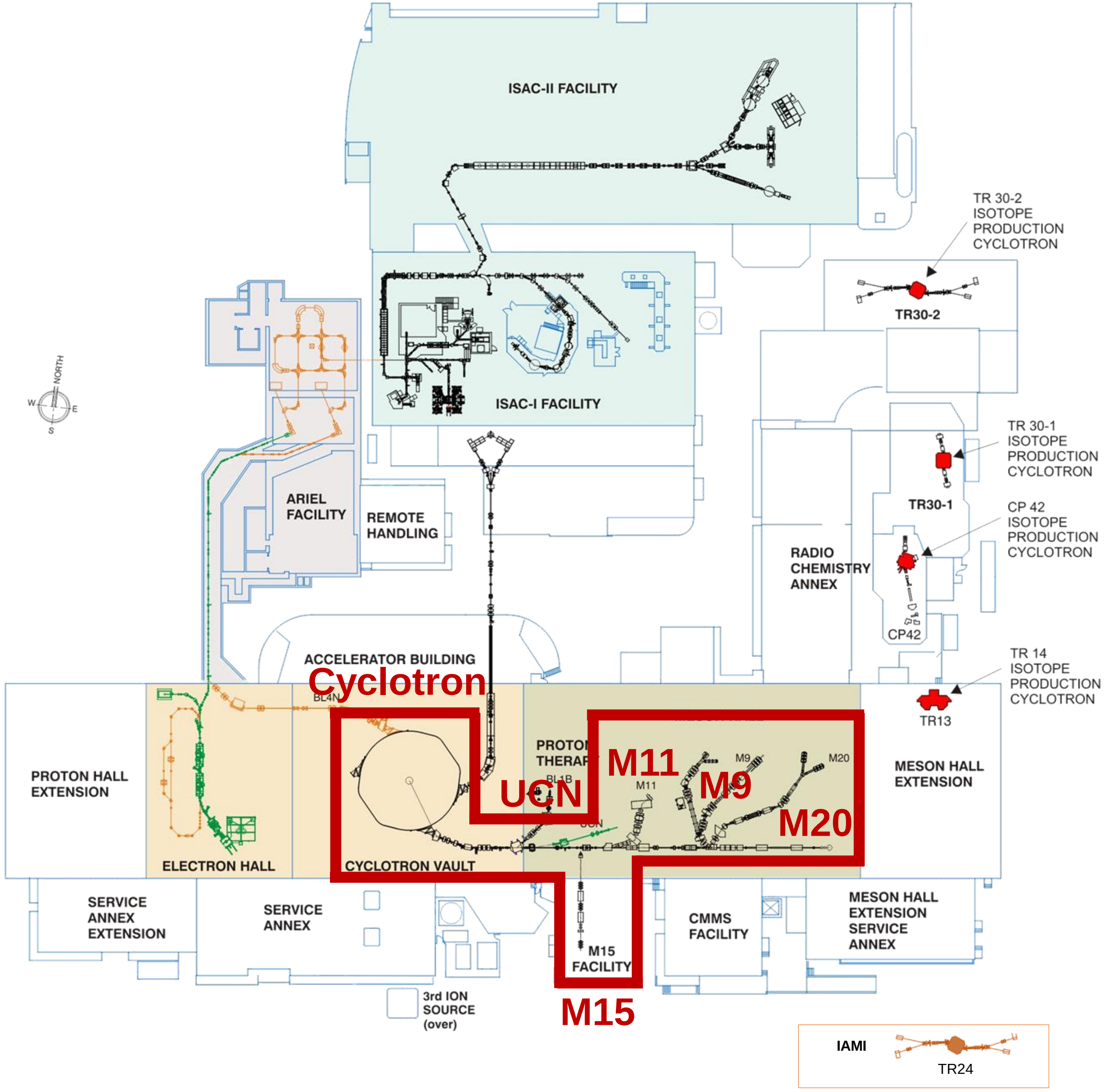
- ^{82}Sr / ^{82}Rb, ^{111}Ag, ^{212}Pb, ^{225}Ac
- Exotic medical isotope R&D, fission and spallation

Electrons from 35 MeV, 10 mA linac

- Preclinical combined FLASH and microbeam radiotherapy

Discovery, accelerated

TRIUMF's Proton, Neutron, Pion, Muon Programs

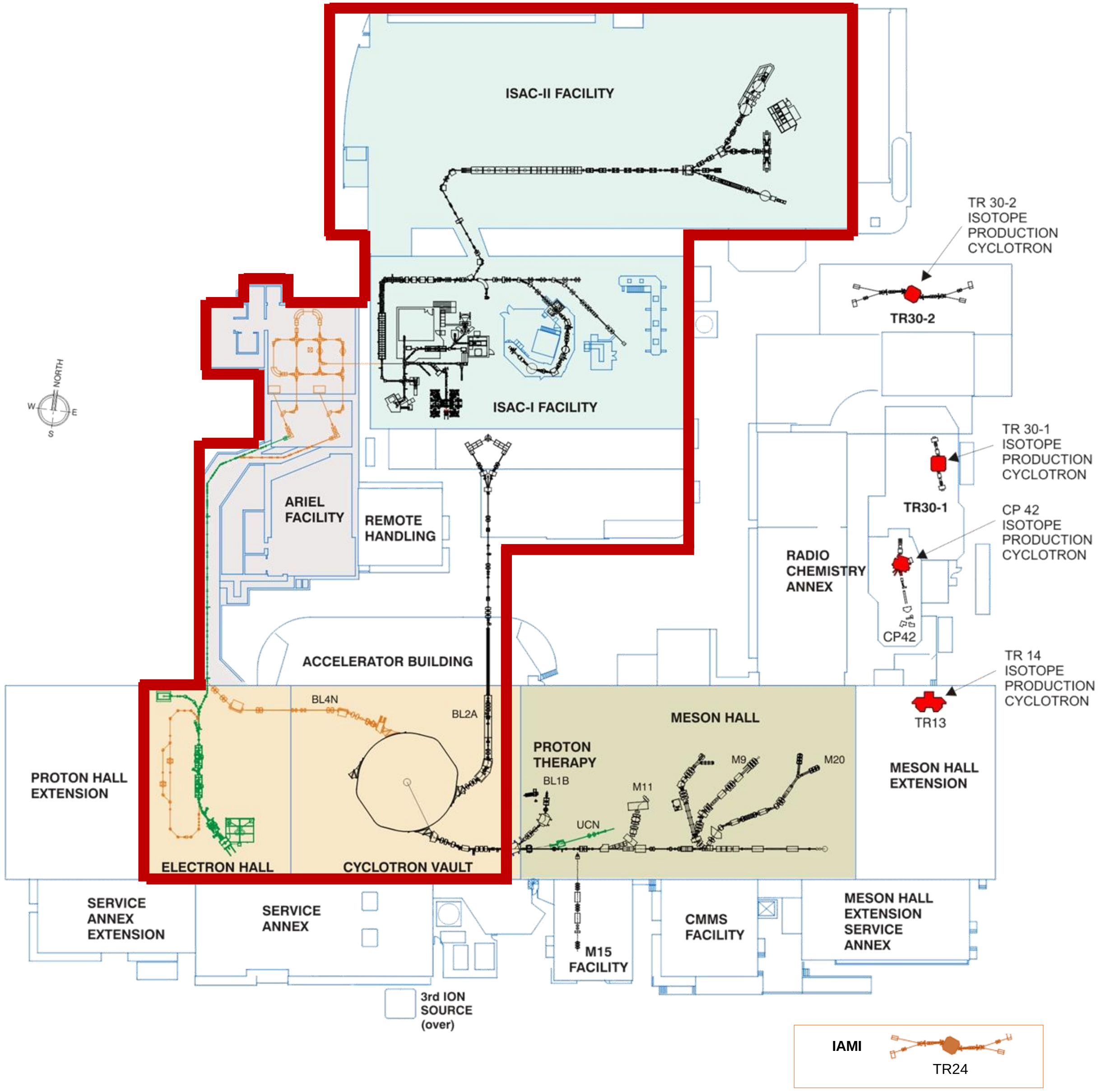


Beamline 1A

Four secondary channels from two production targets

- Pions, muons for material and fundamental science
- UCN (Ultra Cold Neutrons) for nEDM measurement
- Generic sample irradiations
- Commercial electronics irradiations

TRIUMF's RIB Factory



ISAC RIB Production (since 1995)

- 2 target stations
- Highest power ISOL driver with 50 kW 500 MeV protons

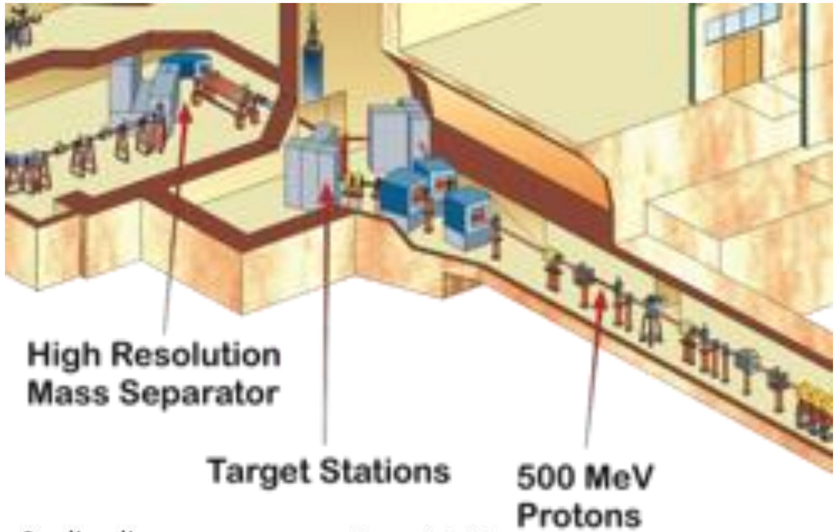
ARIEL RIB production (in progress)

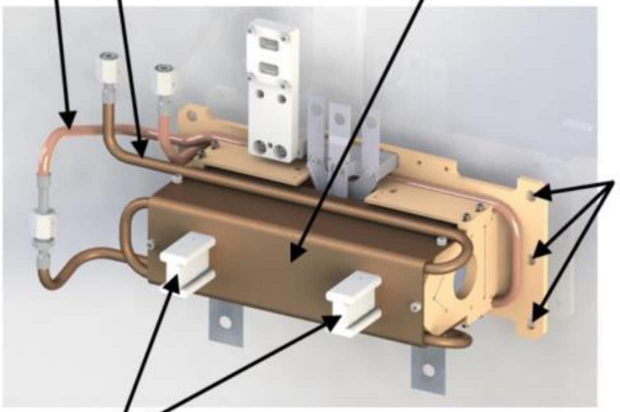
- Two new ISOL target stations
- First high-power electron driver with 100 kW, 30MeV (2021)
- High-power proton driver with 50 kW 500 MeV (2023)

ISAC/ARIEL experimental areas

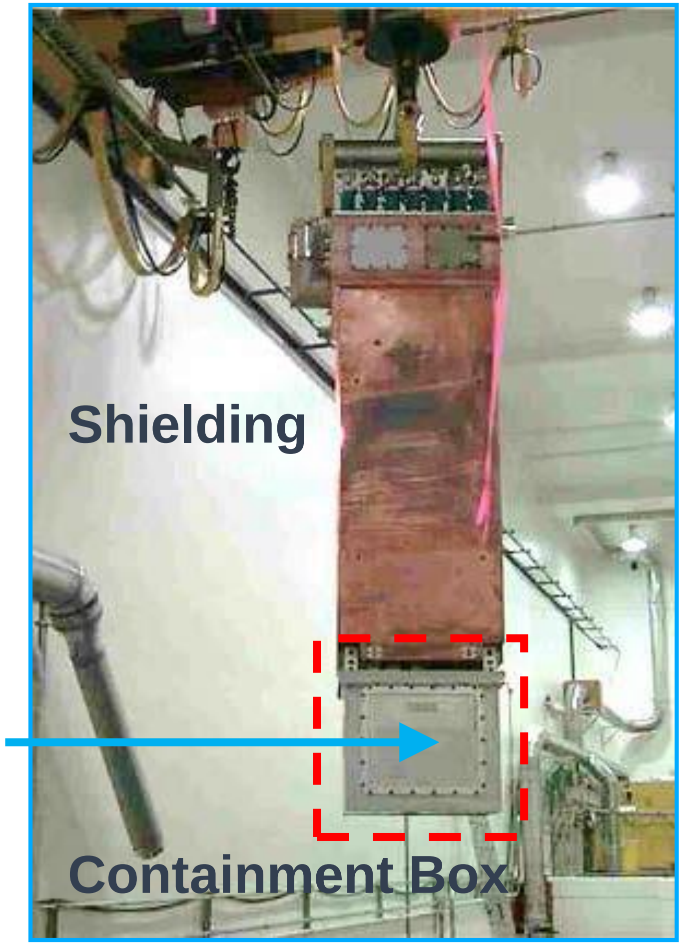
- Low energy ≤ 60 kV
- Medium energy ≤ 1.8 MeV/u
- High energy ≤ 16.5 MeV/u

ISAC – World Highest Power ISOL Target Systems





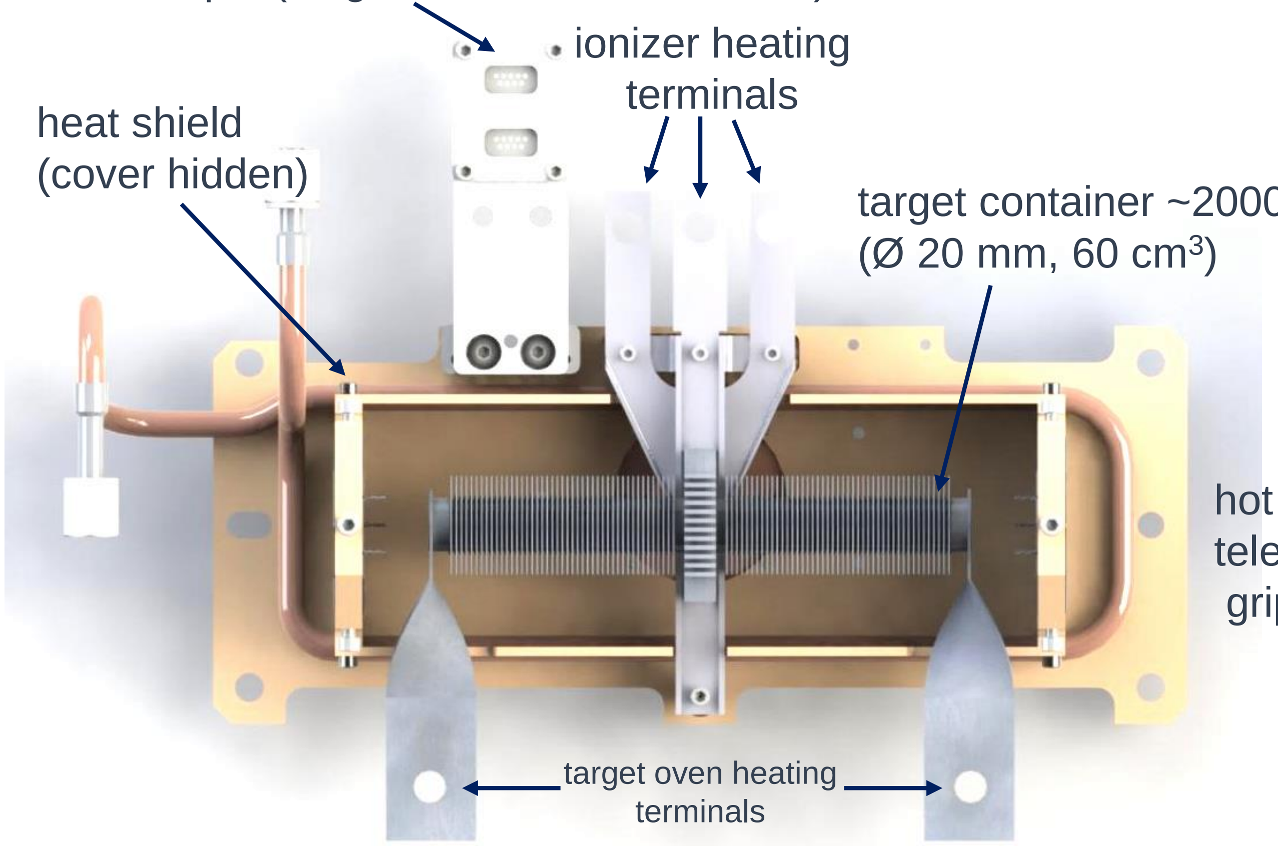
Target assembly mounted in the Target Module containment box

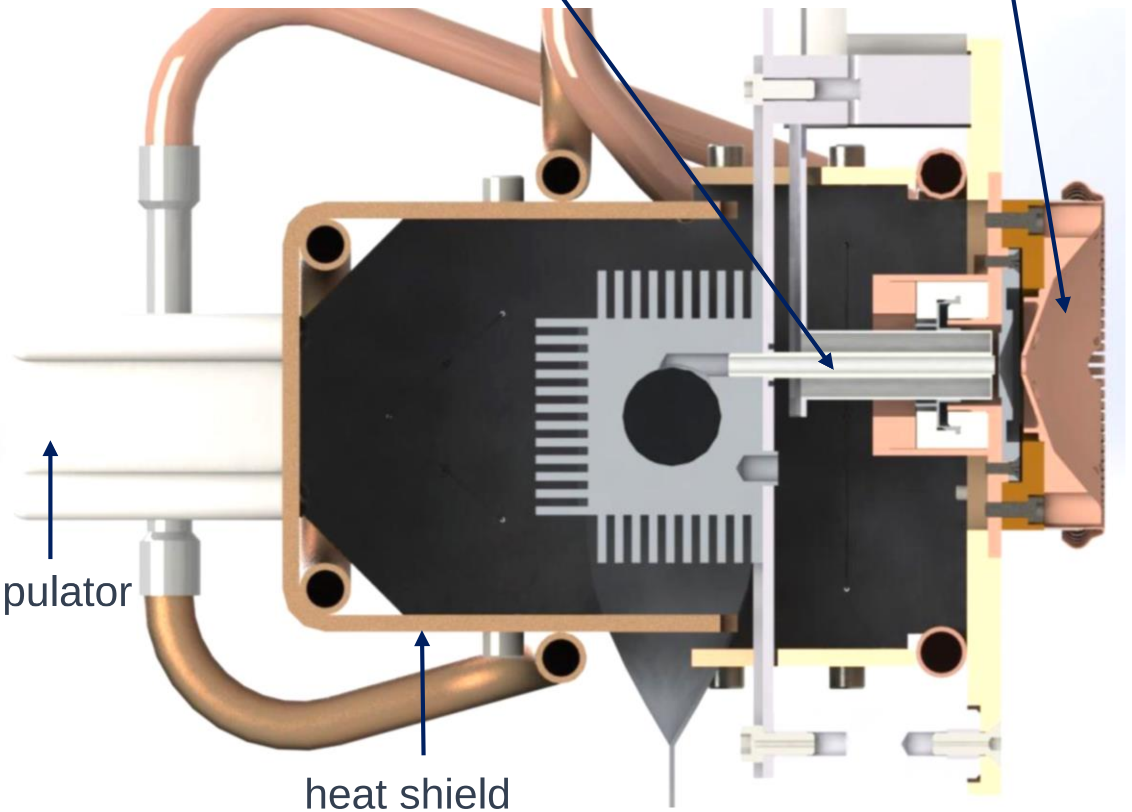


ISAC Target module hanging from remote handling crane

Target module transport to target station

ISAC 50 kW Target Assembly



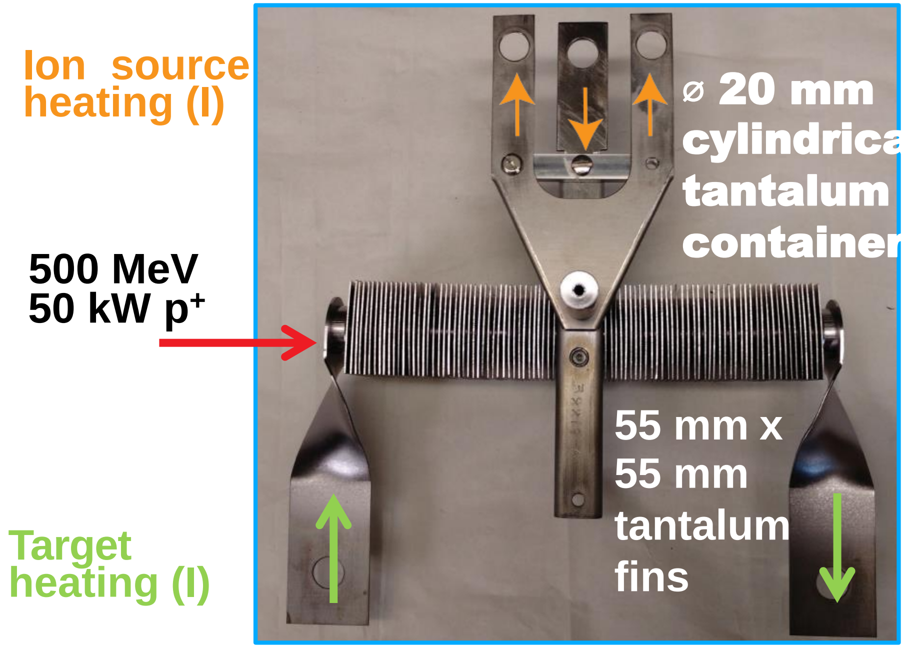


diffusion bonded Ta fins
→ radiative cooling of up to 13 kW
→ 50 kW proton irradiation

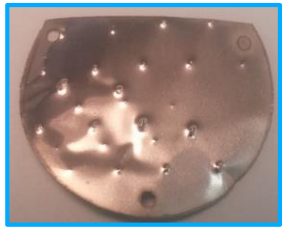
Selected ISAC Target Materials

Axial proton irradiation, used with 500 MeV, up to 100 µA proton driver beams. Tantalum fins increase the effective emissivity to ~0.9.

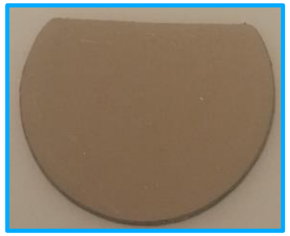
High-power (50 kW) target design



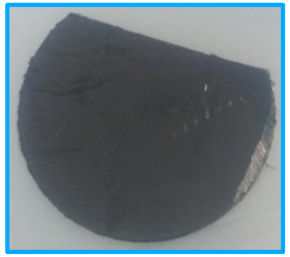
Combination of porous materials for optimized release of short-lived radioisotopes on backing foils for high conductive heat transfer into tantalum container



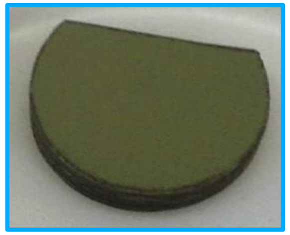
2000: Tantalum or niobium foil discs packed within the tantalum target container.



2008: Discs of SiC_x, TiC_x or ZrC_x cast onto exfoliated graphite foils and packed within the tantalum target container.

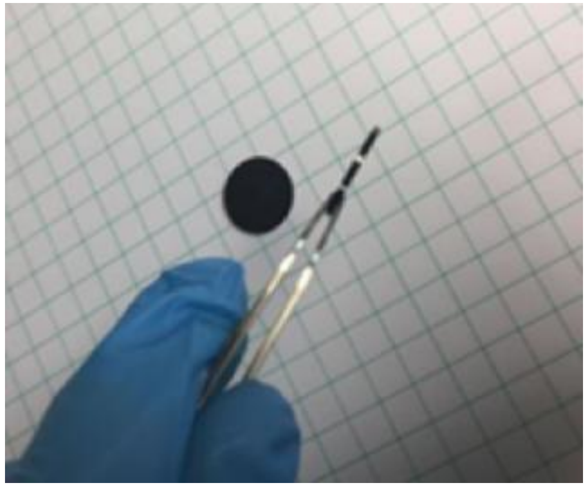


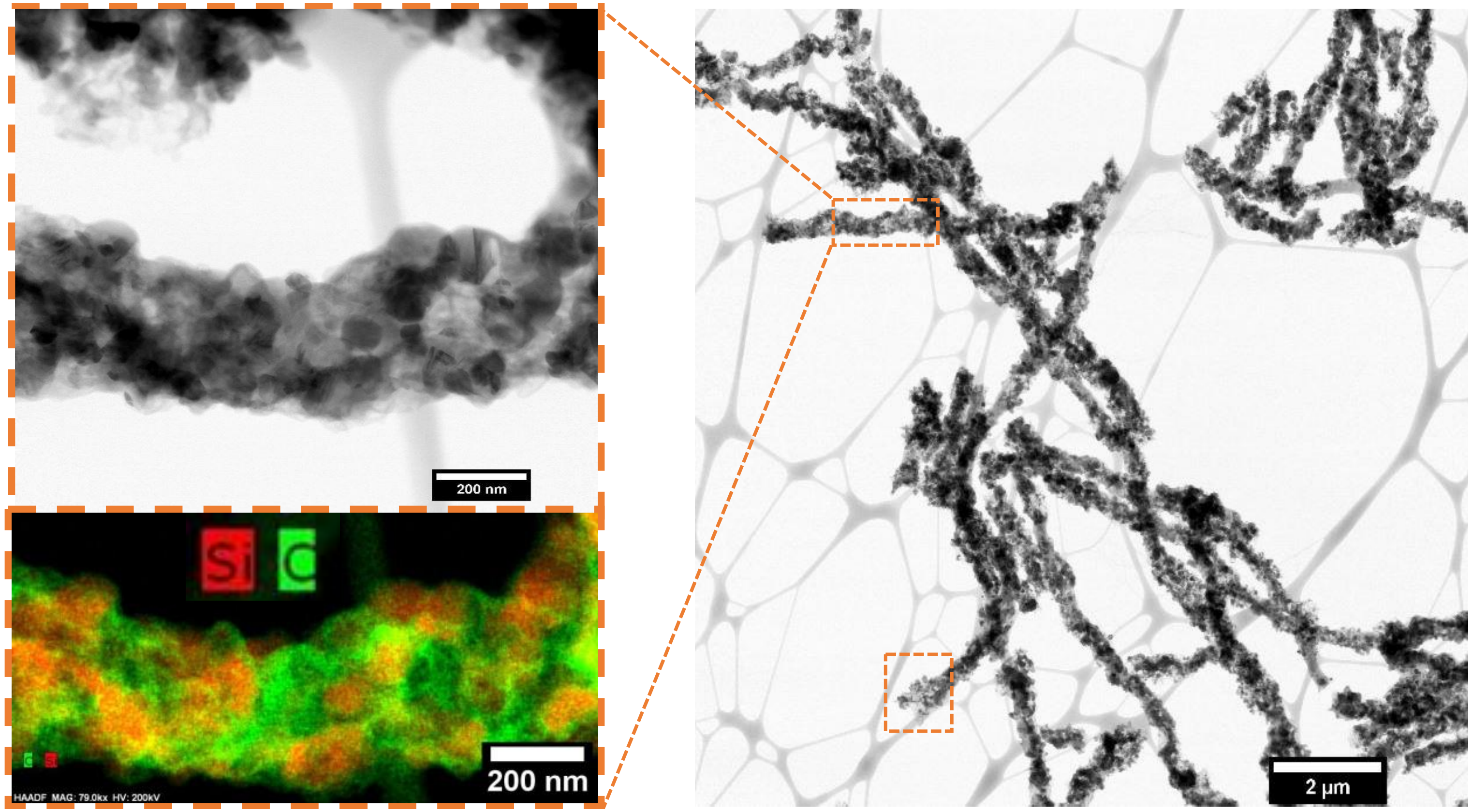
2013: Discs of UC_x cast onto exfoliated graphite foils and packed within the tantalum target container.



2015: Discs of NiO cast onto niobium foils and packed within the tantalum target container.

New Target Materials – Electro Spun SiC Nanofibres





Goal:

- Reduction of particle size, increase of open porosity
- Nanometric stabilization in refractory carbon fibre backbone
- Increased yield of exotic diffusion limited isotopes

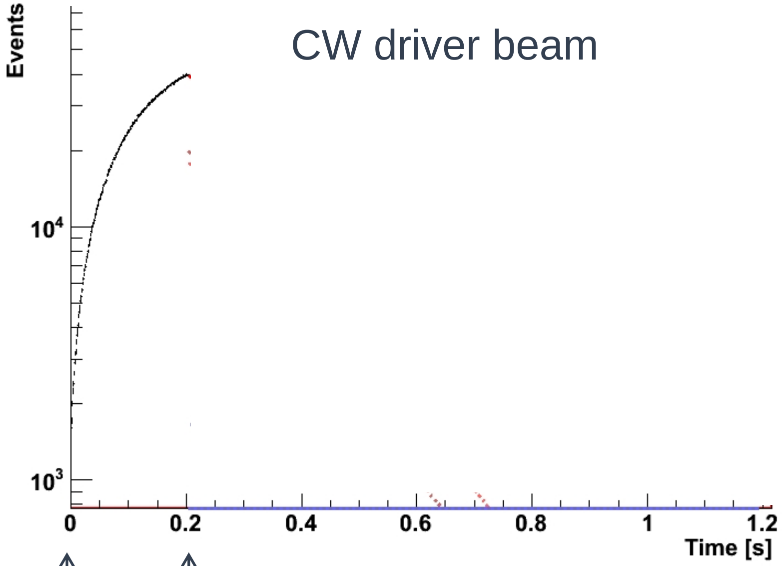
Status:

- Target operated for 15 days at 55 µA
- Very stable operation, no signs of material degradation

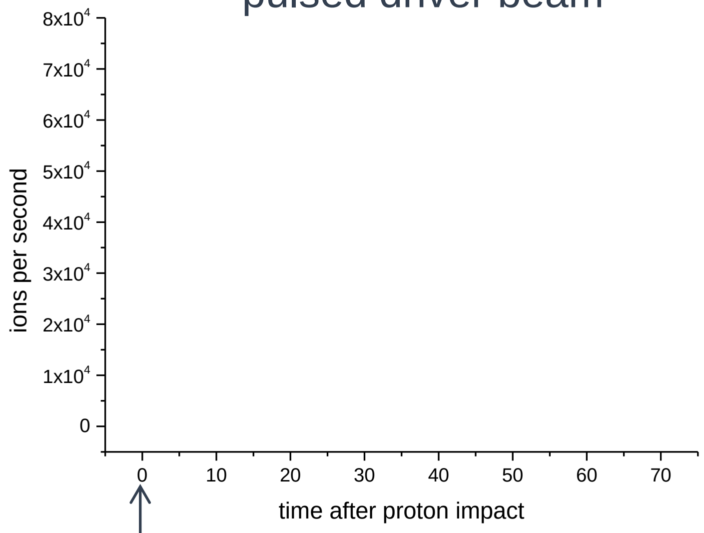
ARIEL
An Independent Driver for TRIUMF’s Rare Isotope Program

Pulsed vs CW Driver Beams for Additional ISOL Driver

CW driver beam



pulsed driver beam



Improved RIB beam diagnostics and development capabilities with pulsed driver beam

radioactive isotope collection stop

driver beam pulse

radioactive isotope collection start

N·H
ELSEVIER
Nuclear Instruments and Methods in Physics Research B 126 (1997) 170–175
NIM B Beam Interactions with Materials & Atoms

Release from ISOLDE molten metal targets under pulsed proton beam conditions

J. Lettry [a,*], R. Catherall [a], G. Cyvoct [a], P. Drumm [b], A.H.M. Evensen [a], M. Lindroos [a], O.C. Jonsson [a], E. Kugler [a], J. Obert [c], J.C. Putaux [c], J. Sauvage [c], K. Schindl [a], H. Ravn [a], E. Wildner [a]

[a] CERN, CH-1211 Geneva 23, Switzerland
[b] RAL, Chilton Didcot, Oxon OX11 0QX, UK
[c] IPN, F-91486 Orsay, France

Table 2
Yields of the short lived mercury isotopes (expressed in Hg atoms per μC of protons) measured under pulsed proton beam conditions and compared to the ISOLDE SC values [19]. The ratio between SC and PS-Booster yields is compared to the ratio of the released fractions

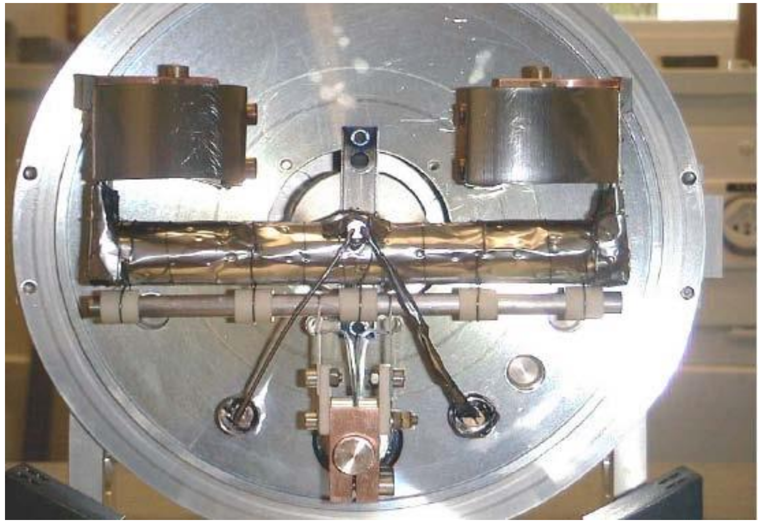
	Yield				Released fraction		
	1.5×10^{13} ppp [1/μC]	2.1×10^{13} ppp [1/μC]	SC [19] [1/μC]	PS/SC	η PS [%]	η SC [%]	PS/SC
^{190}Hg	3.4×10^9	3.9×10^9	4×10^9	0.98	98.8	96.8	1.0
^{180}Hg	105,000	102,000	53,000	1.9	27.4	6.0	4.6
^{179}Hg	6,100	5,500	1,600	3.4	14.3	2.6	5.5
^{178}Hg	105	163	38	4.3	3.1	0.6	4.8
^{177}Hg		1.8	0.9	2.0	1.6	0.4	4.1

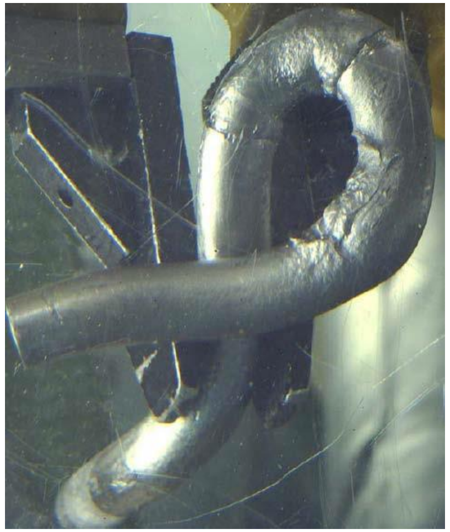
RIB intensity ratio pulsed / CW

Improved isotope release in certain conditions with pulsed driver beam

Detrimental Impact of Pulsed Proton Beam on ISOL Targets

Ruptured liqud lead target assembly after pulsed proton irradiation





Ta-rod after irradiation with $6 \cdot 10^{18}$ protons in 2.4 µs pulses of $3 \cdot 10^{13}$ protons at CERN-ISOLDE

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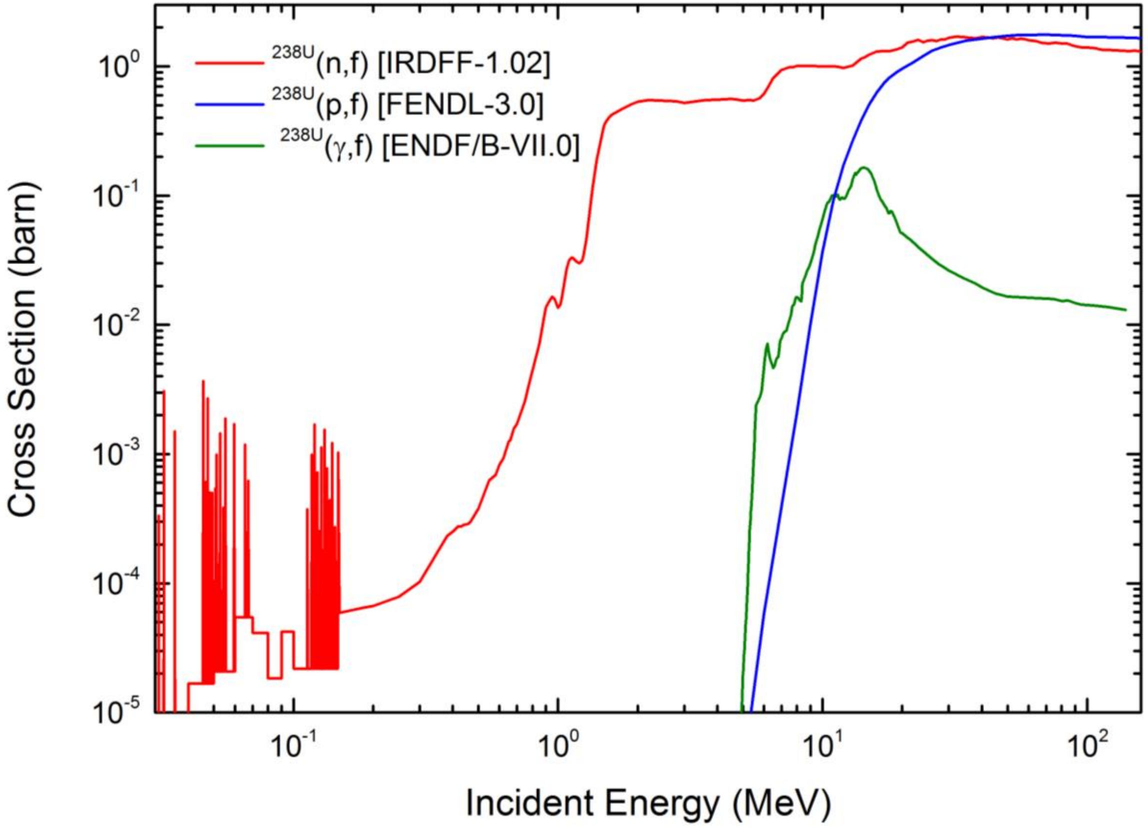
Isotope Production Cross Section for New ISOL Driver

production intensity from $^{238}UC_x$

cross sections

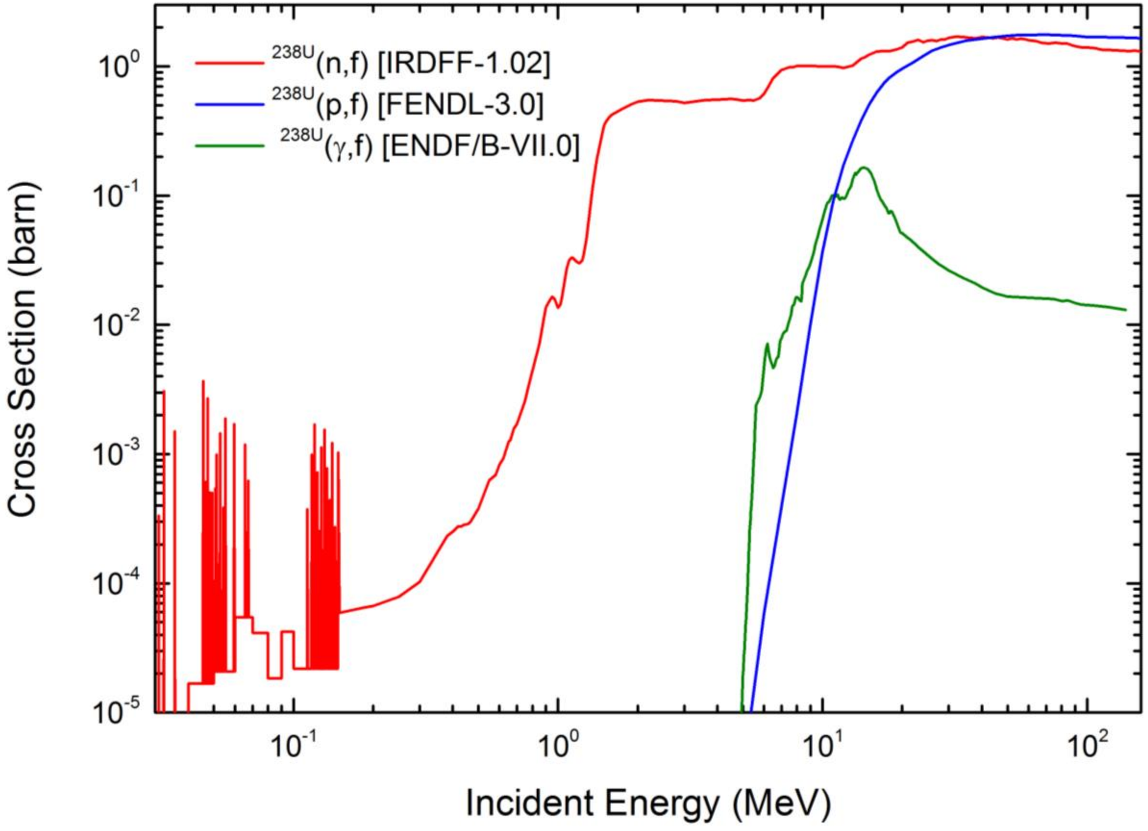


Discovery, accelerated

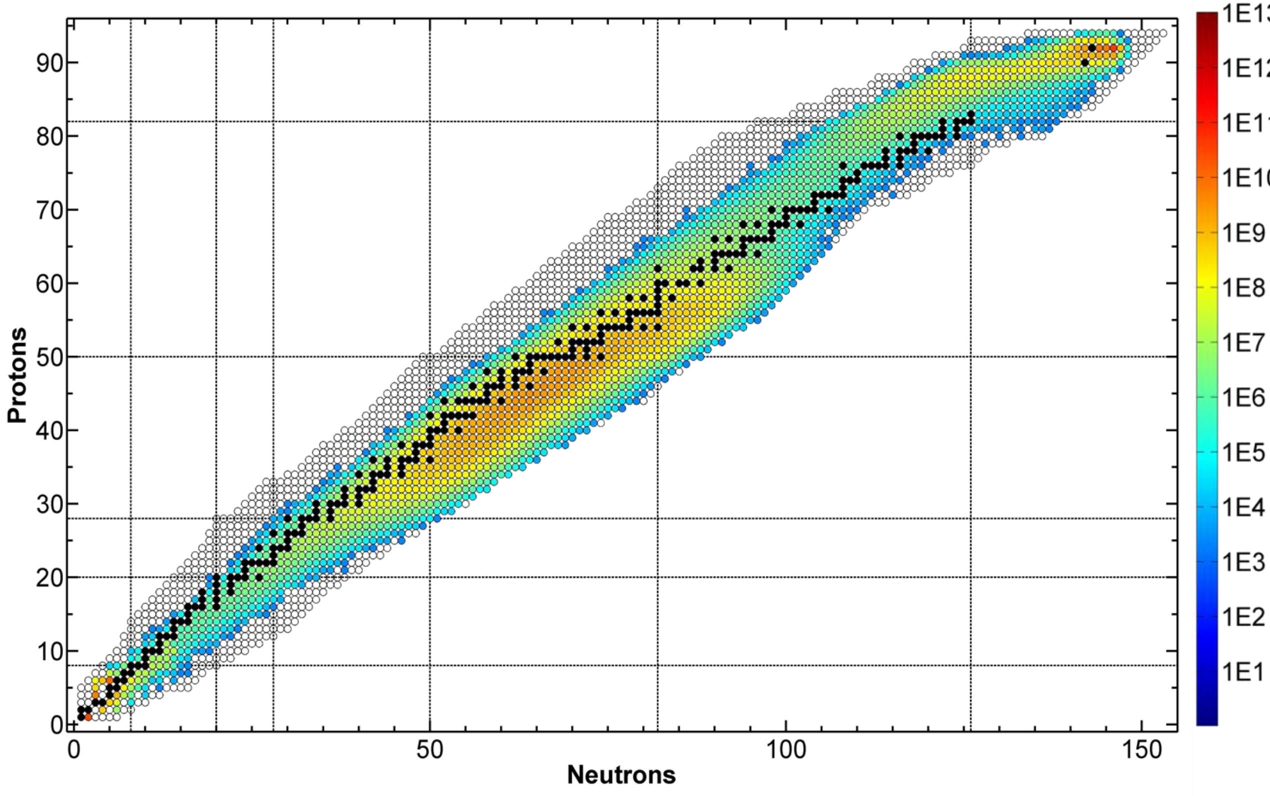
Isotope Production Cross Section for New ISOL Driver

production intensity from $^{238}UC_x$

cross sections



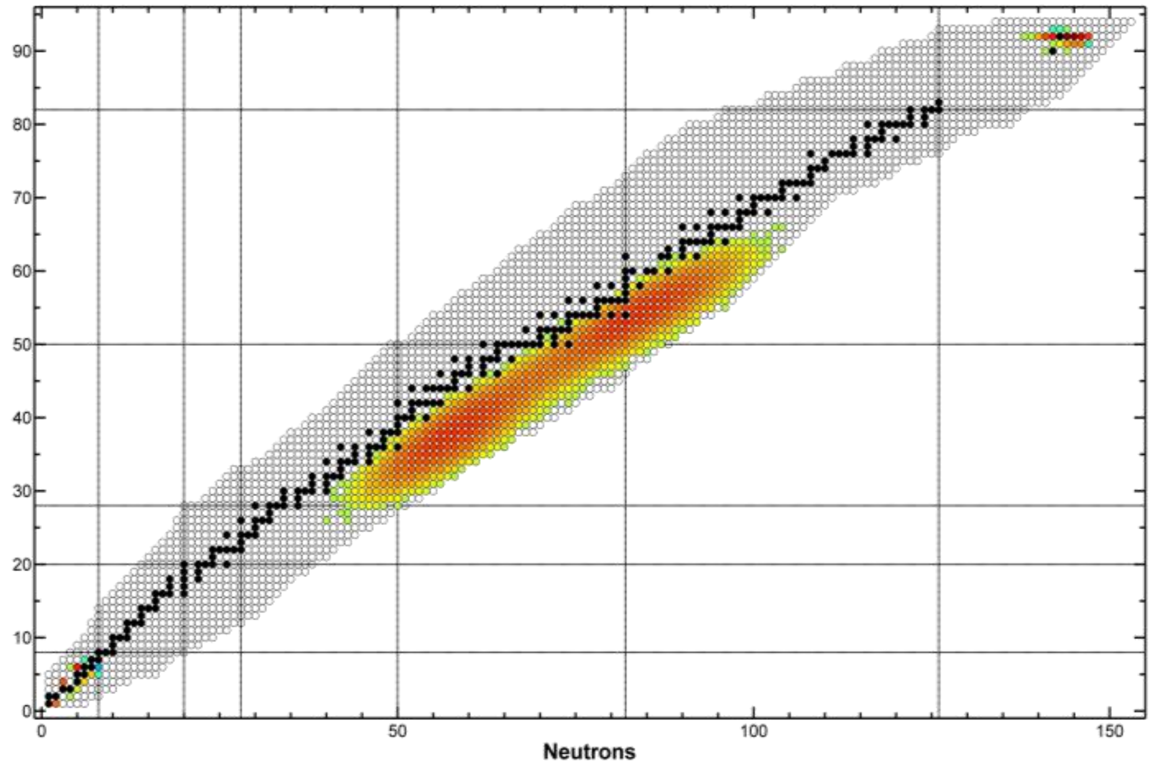
500 MeV x 10 µA protons [1/s]



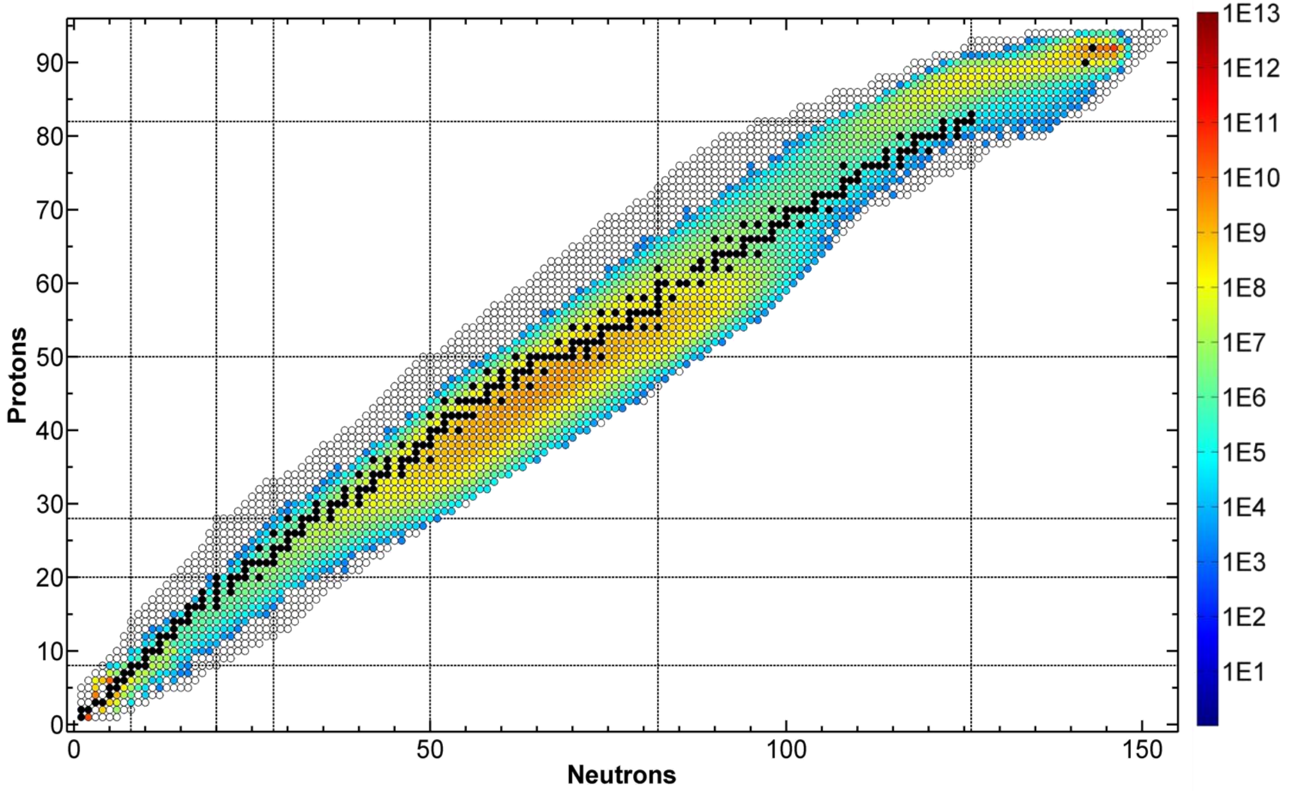
Isotope Production Cross Section for New ISOL Driver

production intensity from $^{238}UC_x$

50 MeV x 10 mA electrons [1/s]

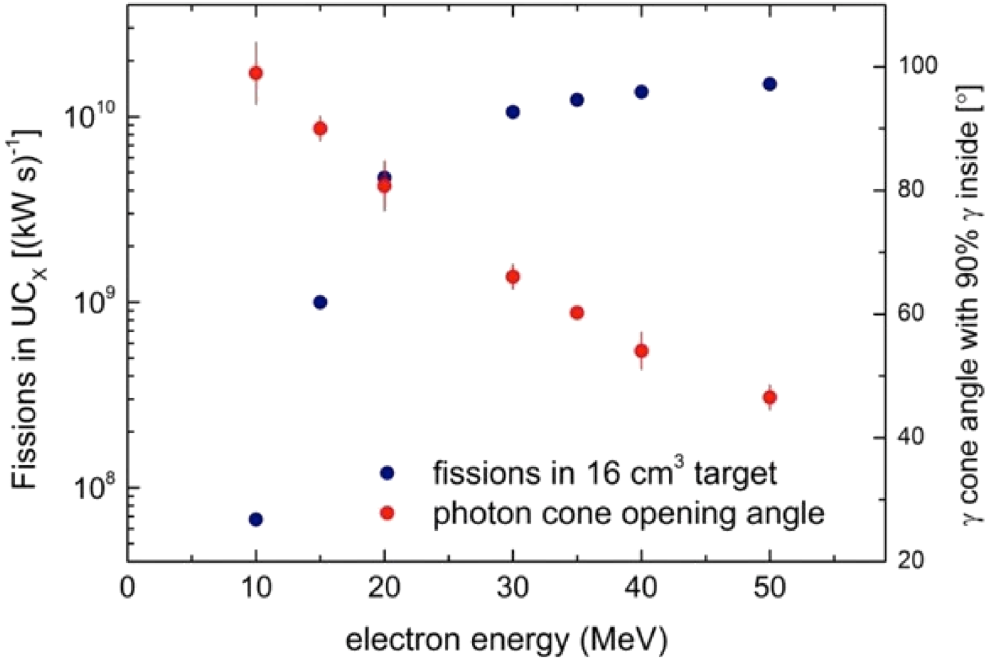


500 MeV x 10 µA protons [1/s]

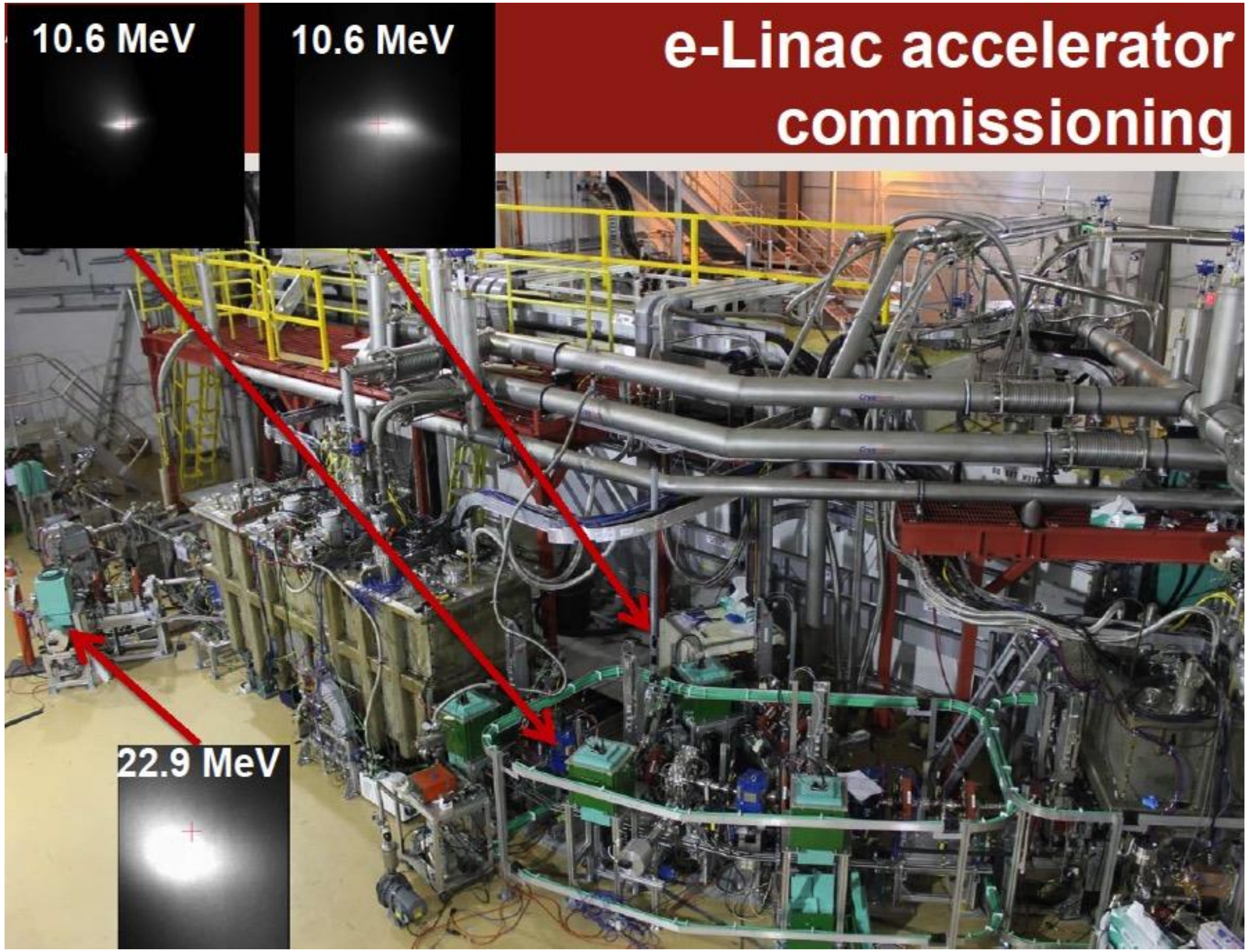


- Pure n-rich products from photofission
- Production cross section reduced in comparison to high-energy hadrons

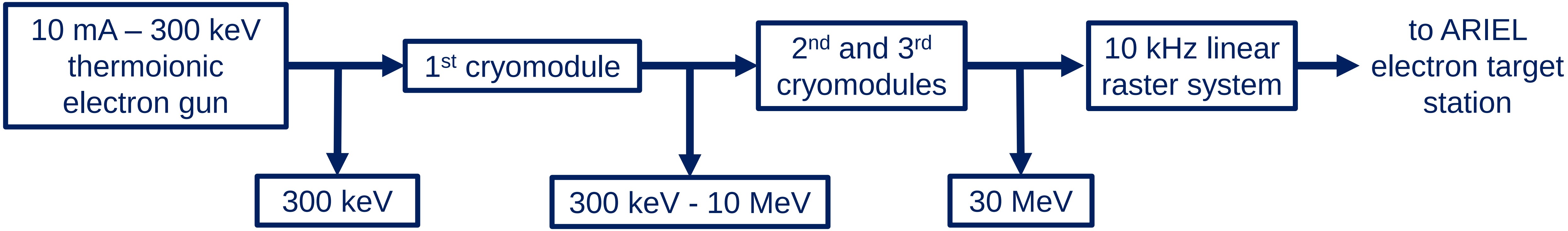
New e-linac Driver for RIB Production



- 650 MHz, 300 keV, electron gun
- superconducting RF, 1.3 GHz, 2 K
- Electron energy ≥ 35 MeV
- Electron beam power up to 500 kW



e-linac Beam Parameters



	CERN HiRadMat Proton Beam	TRIUMF e-linac Beam Parameters
Beam Energy	440 GeV	300 keV – 35 MeV
Beam Pulse Energy (max)	2.4 MJ (7.95 µs)	1 – 350 J (1 ms)
Range	meters	µm to mm
Pulse power deposition	A few hundred J/mm	1-300 J/mm
Pulse Length	7.95 µs (max)	1 µs - CW
Number of Bunches	1 to 288	unlimited
1 σ r.m.s. beam radius	0.5 to 2.0 mm (standard)	0.3 to 15 mm
Pulse rate	Hz	Hz to kHz (accelerated aging tests possible)

Irradiations and thermal shock studies of small samples with limited or no radioactive activation → complementary to HiRadMat

ARIEL e-γ Converter Test Stand

300 keV to 30 MeV,

up to 10^{22} electrons/day, 0.1 – 12 mm FWHM

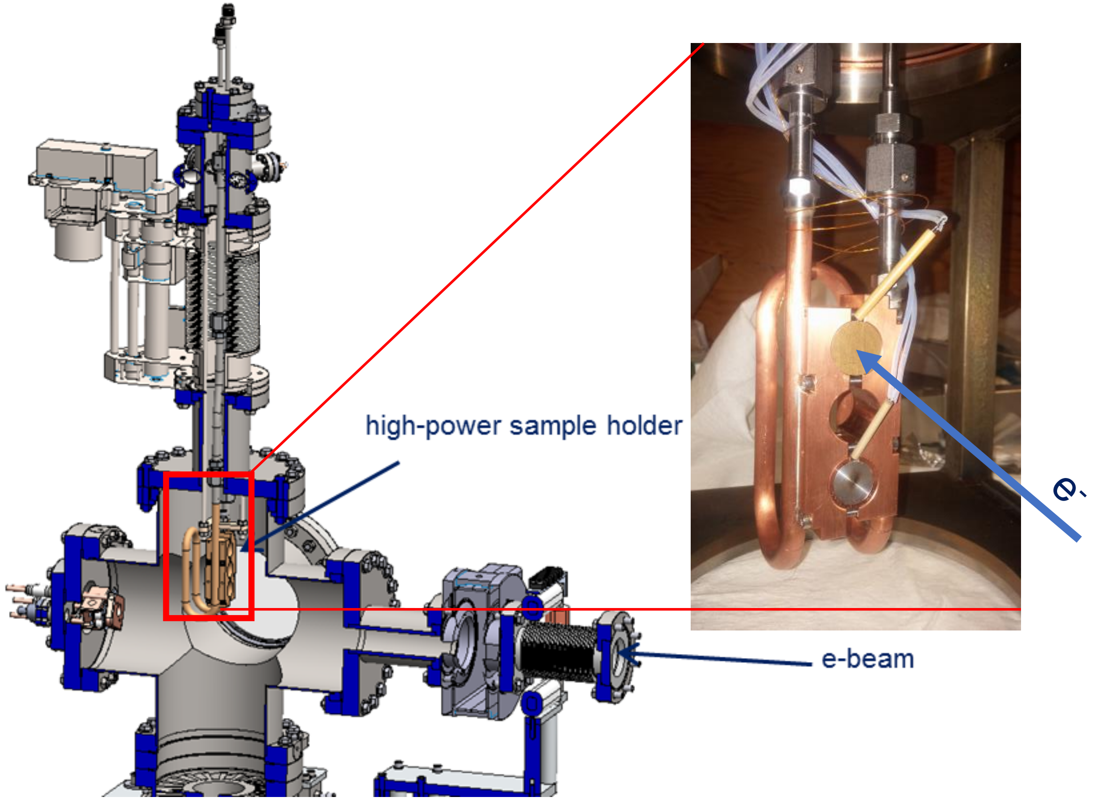
high and variable thermal shocks

High-Z / aluminum interface at risk:

- Thermal stresses (100 kW beam, thermal cycles)
- Radiation damage / radiochemistry
- Irradiations of up to 3 weeks

Experimental setup:

- Water-cooled sample holder
- Several material test campaigns concluded
- Power deposition density of up to several MW/cm^3
- 300 keV beam to avoid activation (30 MeV possible)



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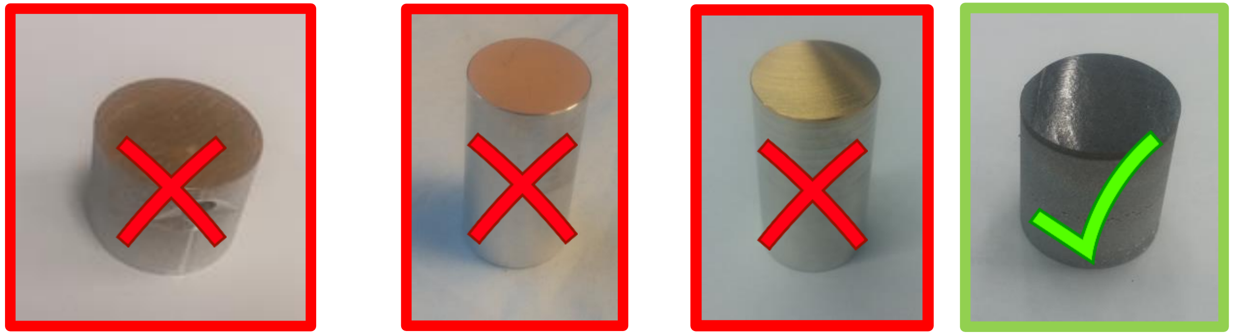
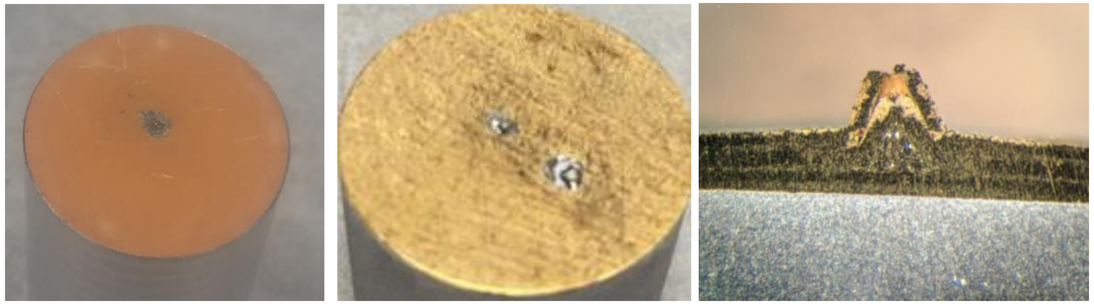
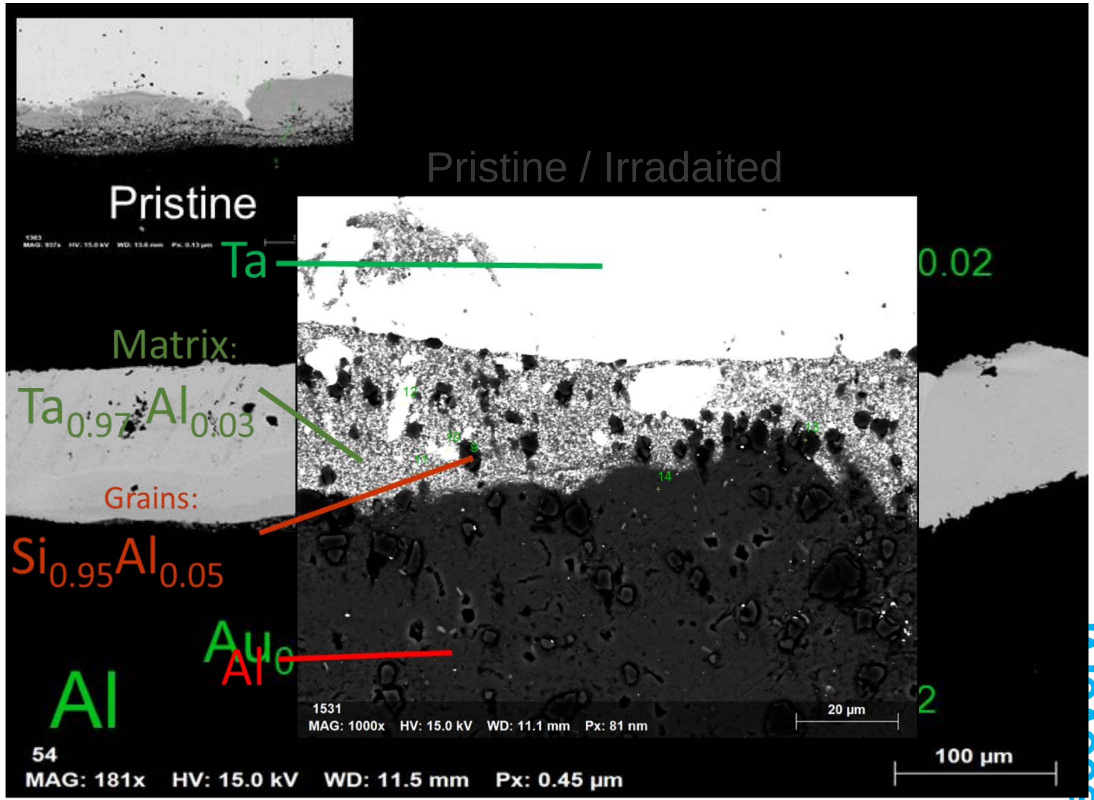
Cycle Resistance of Au and Ta on Aluminum

Au-Al Expl. Weld | **Au-Al** E.D. + Ni | **Au-Al** E.D. | **Ta-Al** Expl. Weld







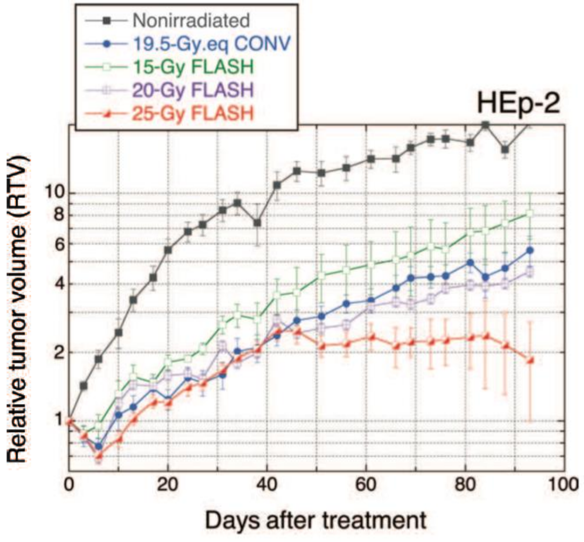
<u>Outcome gold on aluminum:</u>

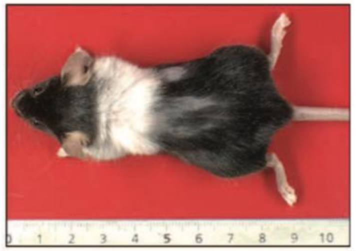
- Temperature increase during irradiation
- Radiation-enhanced Au-Al diffusion
- Formation of brittle intermetallic

<u>Outcome tantalum on aluminum</u>

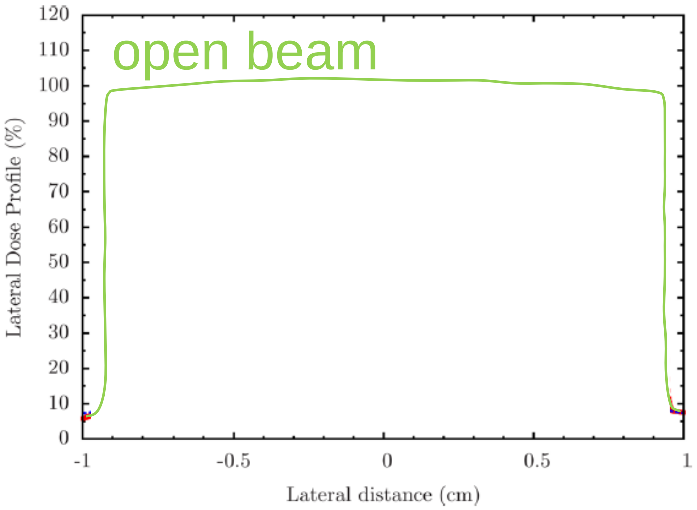
- Temperature stable over 500 h of irradiation
- No change of surface morphology
- No major evolution of interface
- No-radiation enhanced diffusion

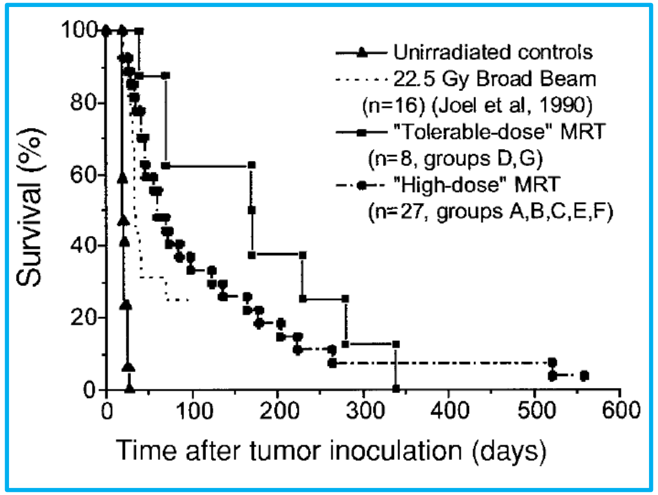
New Possibilities with Pulsed Beam
Example: Combined FLASH and Microbeam Radiotherapy Development





20 Gy FLASH dose
Hair depigmentation, but
no epilation or skin ulceration





Conventional dose rate ~0.03 Gy/s
Conventional beam spot size ~ cm

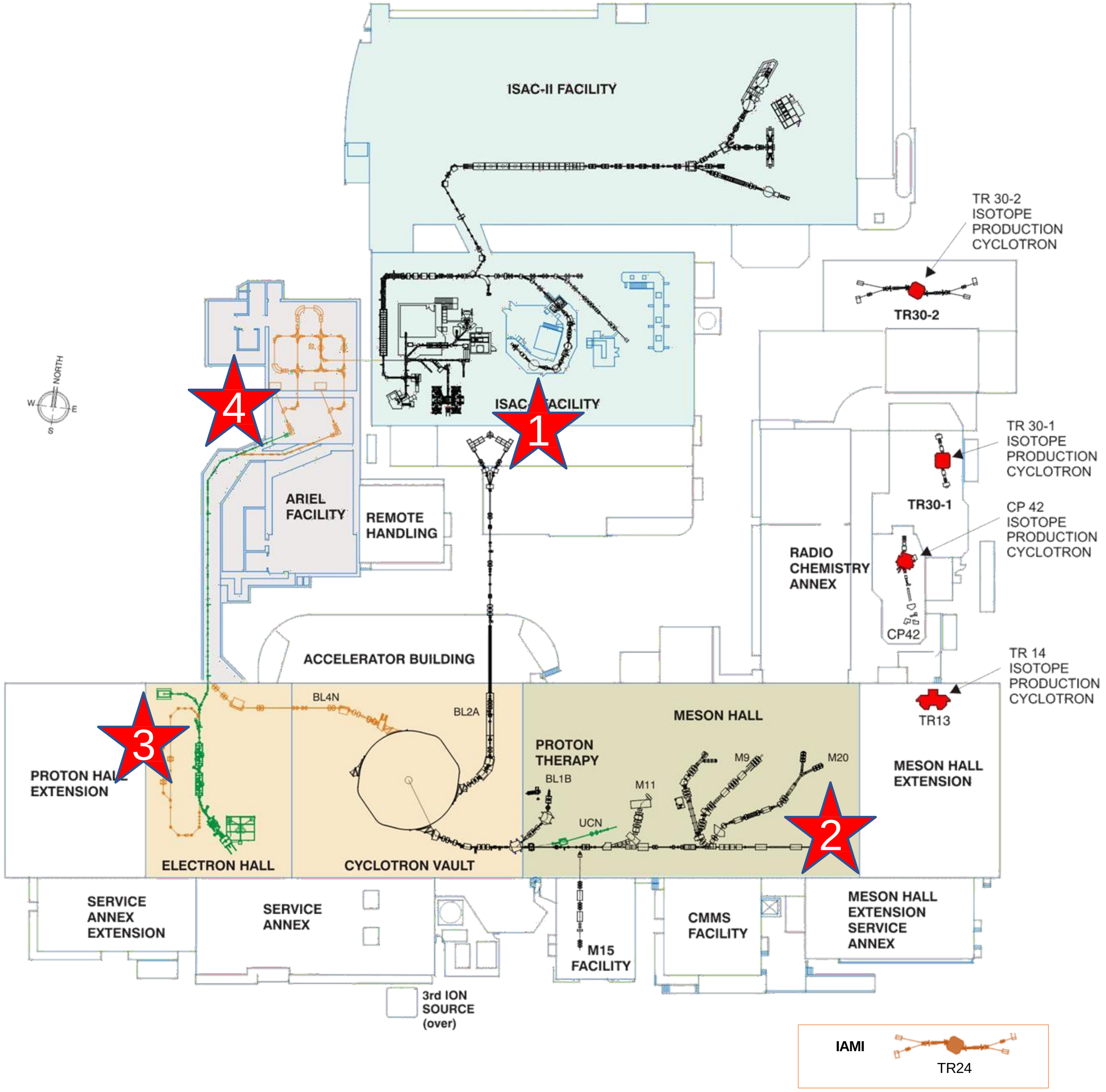
Requirements for irradiations at TRIUMF e-linac for combined FLASH-MRT studies:

- FLASH dose rate ~40 Gy/s
- Microbeam beam spot size < 100 µm

→ Beam pulses inducing unprecedented power density in material composite of electron-to-gamma converter

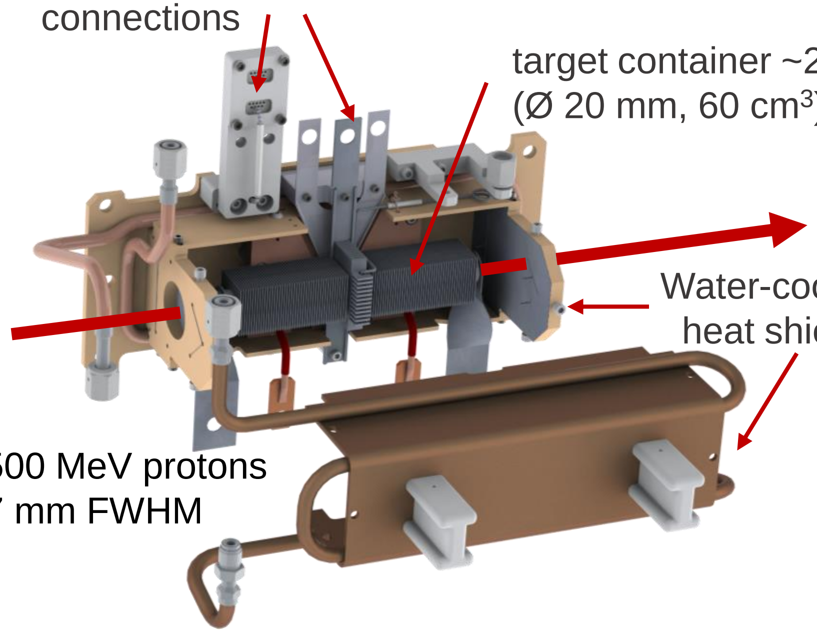
Direct proton beam irradiation capabilities

TRIUMF Irradiation Locations

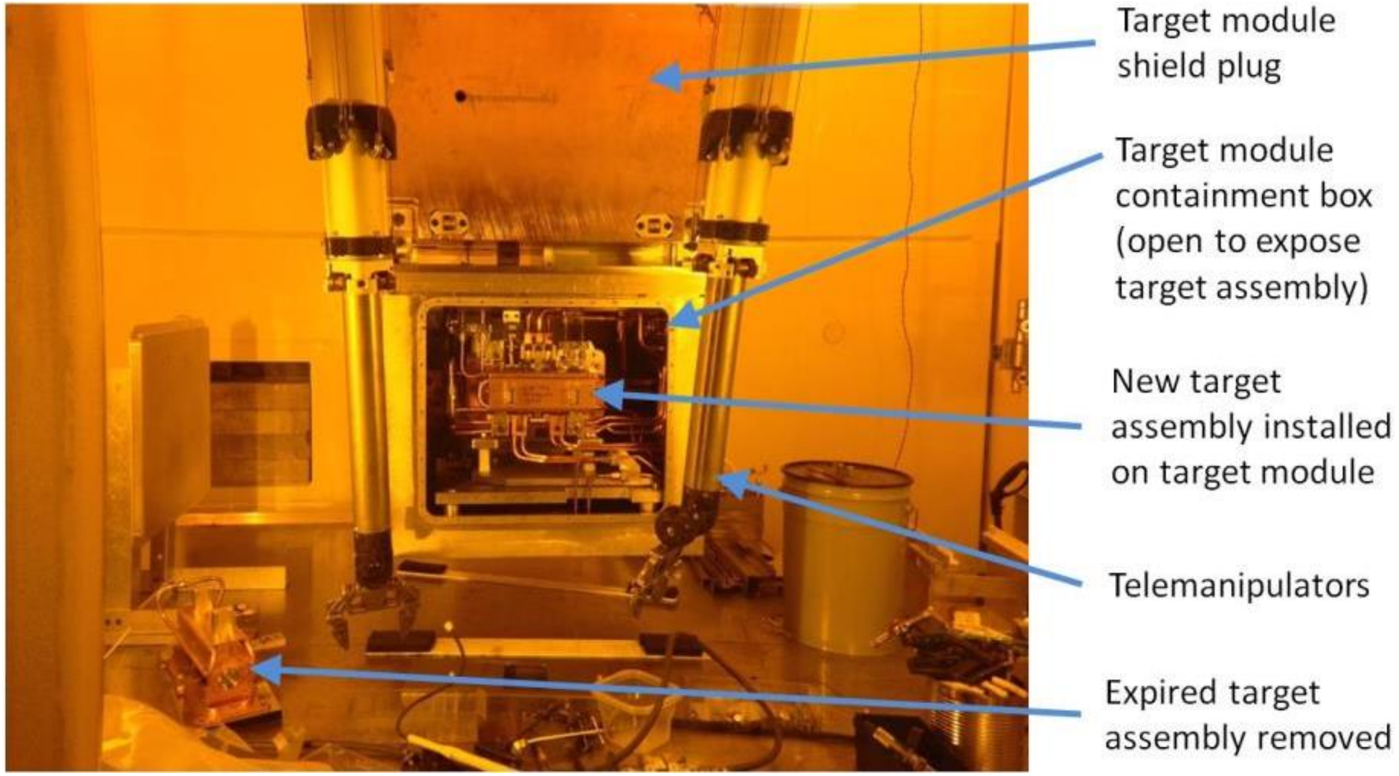


1. ISAC, 500 MeV protons, ≤100 µA
2. IPF, 420 MeV protons, ~50 µA
3. e-linac, 35 MeV electrons, ≤10 mA
4. ARIEL, 500 MeV protons, ≤100 µA

Parasitic Sample Irradiations at TRIUMF-ISAC



- Target exchange in hot cell every 2-5 weeks
- 10 – 12 targets per year
- PIE on every target



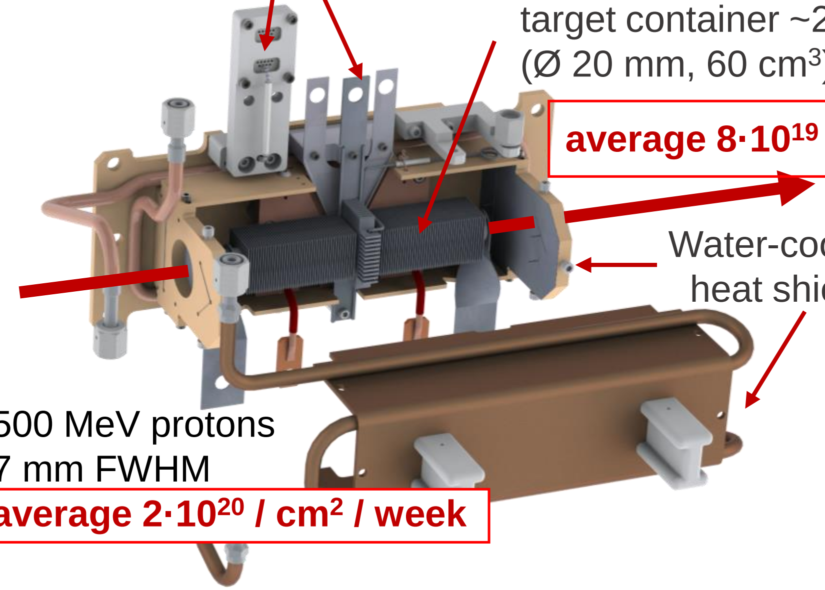
target materials:

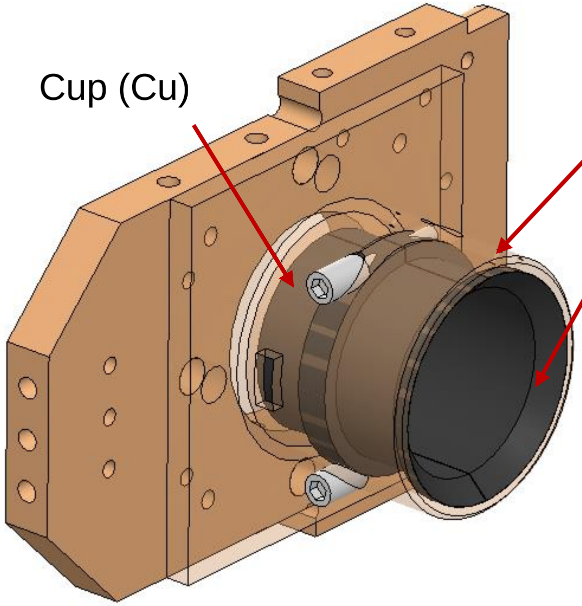
- UC_x
- UO_2
- ThO
- Nb
- Ta
- TaC
- NiO
- ZrC
- TiC
- SiC

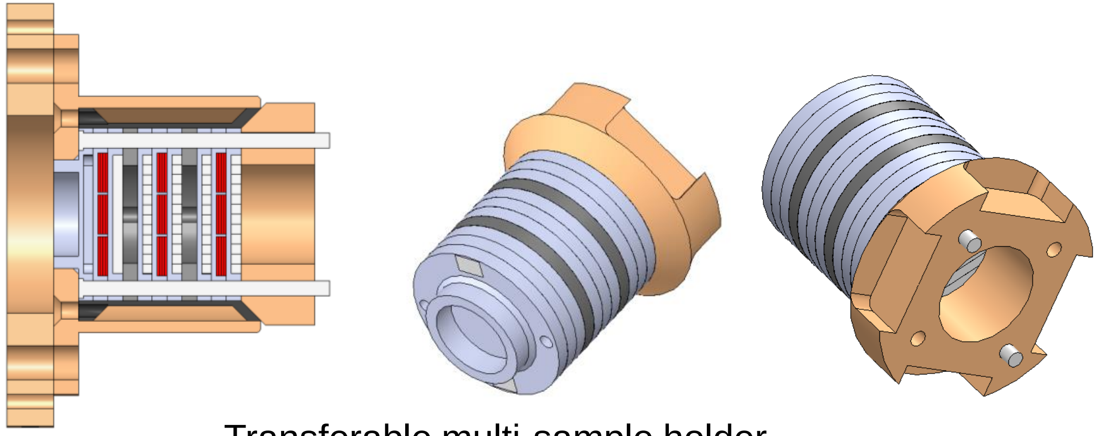
ion sources:

- surface
- resonant lasers
- FEBIAD
- IG-LIS

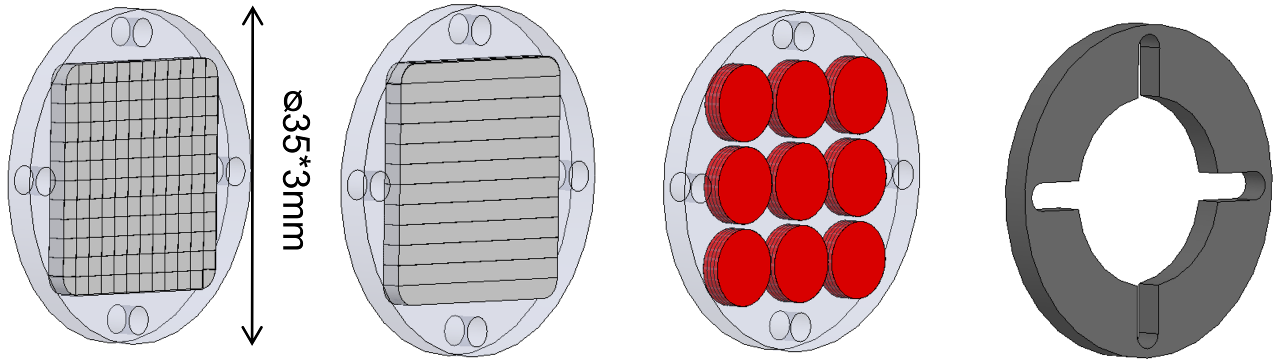
Parasitic Sample Irradiations at TRIUMF-ISAC







Transferable multi-sample holder



144 (2*2*2)mm samples to be sorted and cut for SEM.

12 (2*2*24)mm samples for dilatometry

8⌀*(0.5-2)mm samples for SPT

Spacer

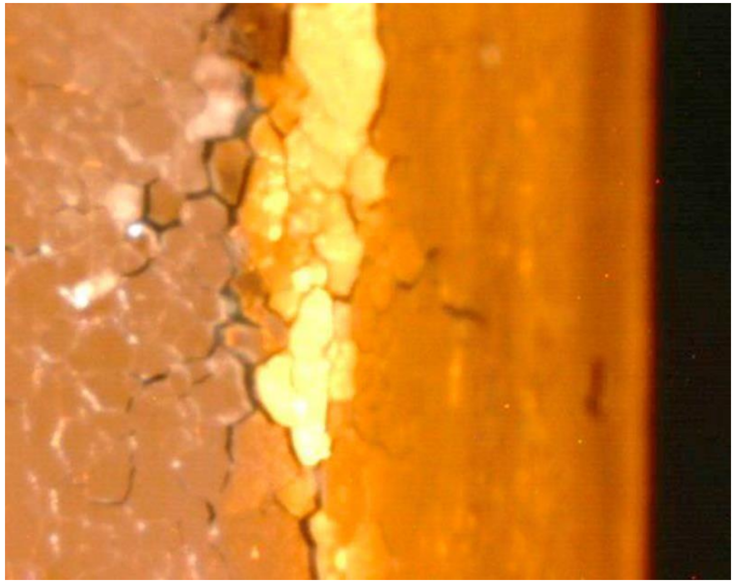
Post-Irradiation Examination and Sample Extraction

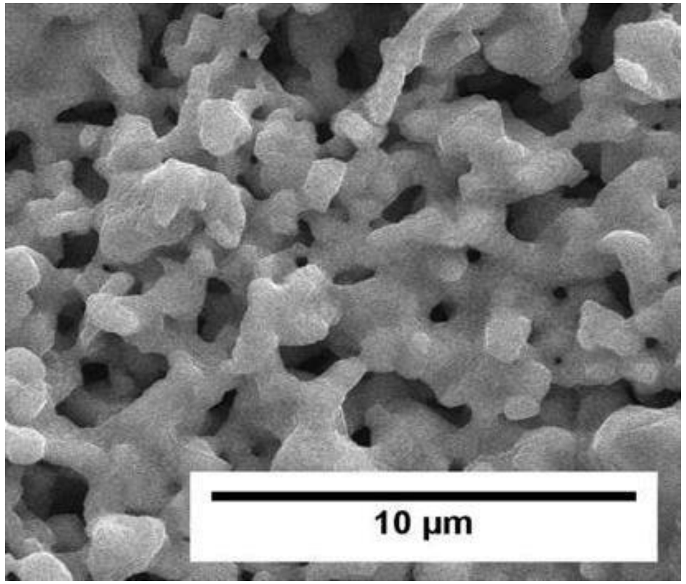
Available in ISAC radiation laboratories:

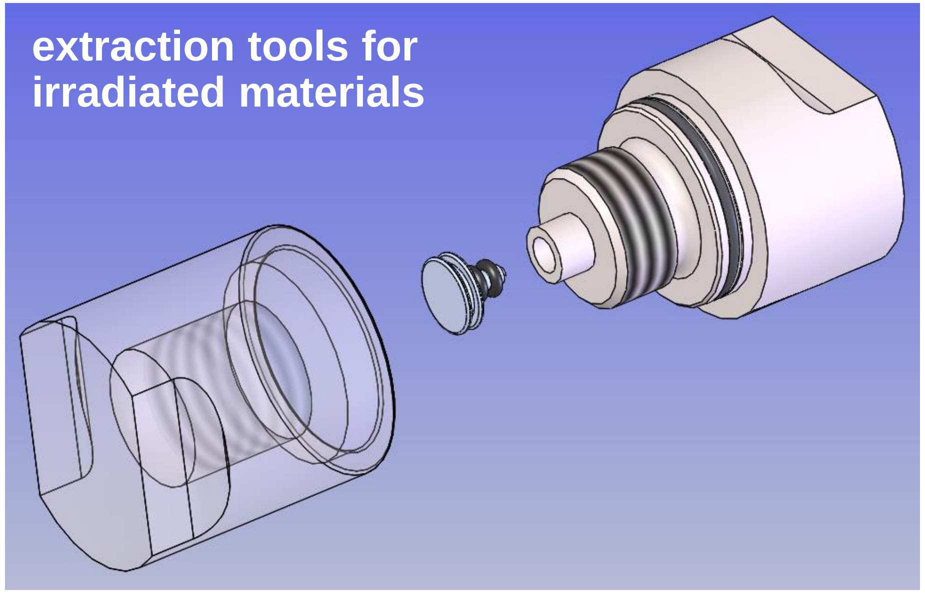
- XRF, SEM
- Optical microscopy
- Pycnometer
- 2000ºC furnaces, diffusion studies
- Emissivity, heat conductivity meas.
- Type A and B packaging and shipping

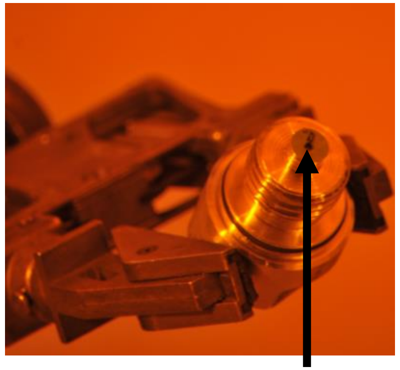
Available in vicinity for activated samples (< 100 µSv/h):

- TEM, SEM, FIB, AFM
- XRD
- Tensile, impact strength, hardness, corrosion testing
- …









UCx sample after irradiation

Supply of radiation aged samples for thermal shock studies at HiRadMat?

TRIUMF Remote Handling

Continuous development of components and systems for operation in kGy – GGy dose fields.

RH robotics development

TRIUMF RH specialists assisting in T2K target repair

Daily handling, processing and shipment of radioactive samples.

PIE of HiRadMat samples within existing CERN-TRIUMF MoU?

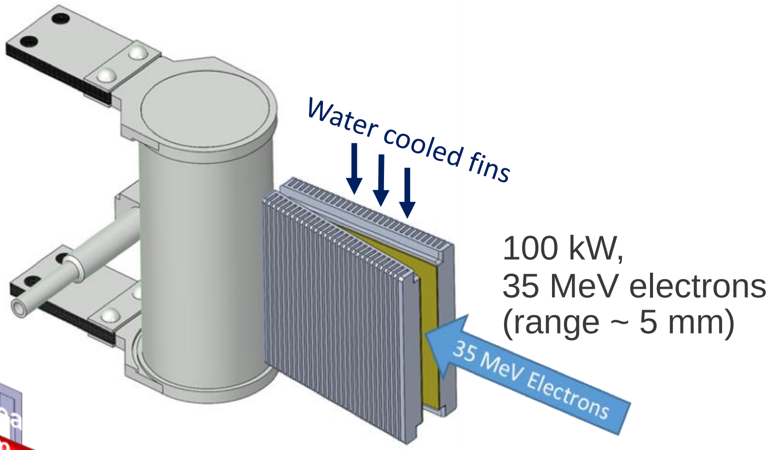
Hot cell facilities

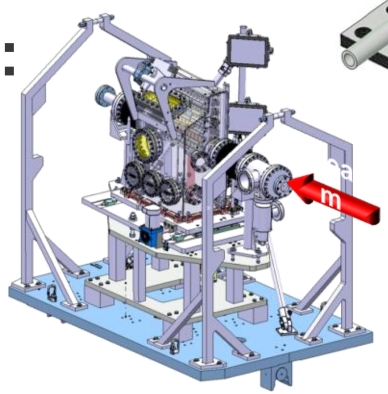
How is HiRadMat Relevant to TRIUMF?

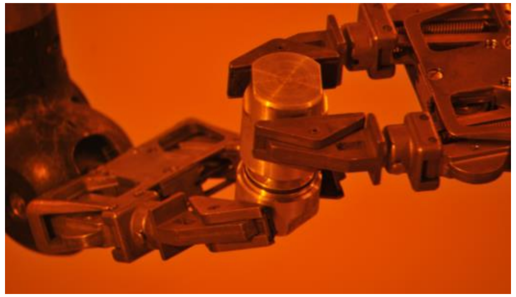
- Irradiations at HiRadMat for development of composite TRIUMF pulsed electron beam targets

Possible collaborations (formal or informal):

- Target station development
- Remote handling
- PIE of samples previously irradiated at HiRadMat
- Beam and sample instrumentation







6th RaDIATE Collaboration Meeting

Radiation Damage in Accelerator Targets Environments

TRIUMF

December 9-13, 2019
Vancouver, Canada

Thank you
Merci

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