Radioactive Ion Beams at the HRIBF

Present Status and Future Development Plans

HRIBF Workshop - Near and Sub-barrier Fusion of Radioactive Ions with Medium and Heavy Targets

December 2-3, 2005

Oak Ridge, TN

Dan Stracener
Physics Division, ORNL

hribf Home

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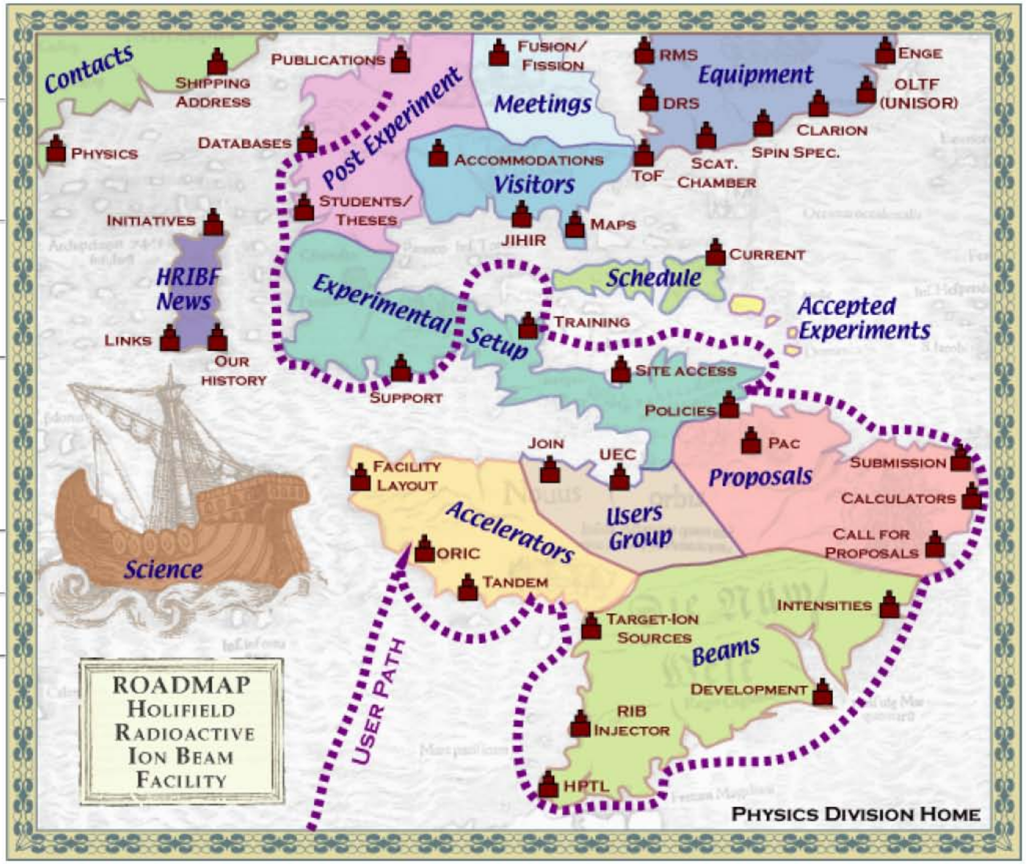

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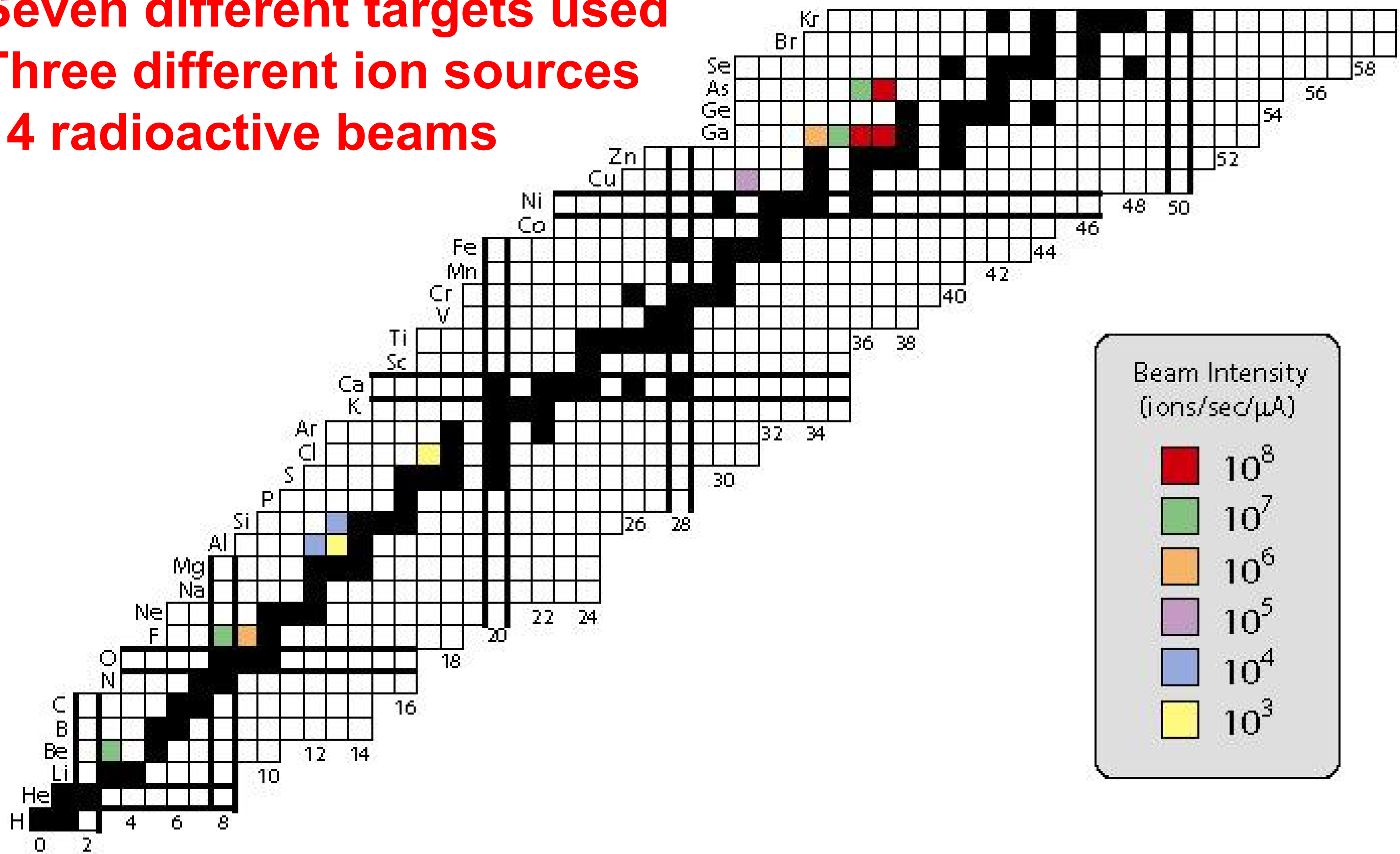
This file last modified Wednesday July 13, 2005

UT-BATTELLE

Proton-rich Radioactive Ion Beams

- **Seven different targets used**
- **Three different ion sources**
- **14 radioactive beams**



Accelerated Proton-rich Radioactive Ion Beams

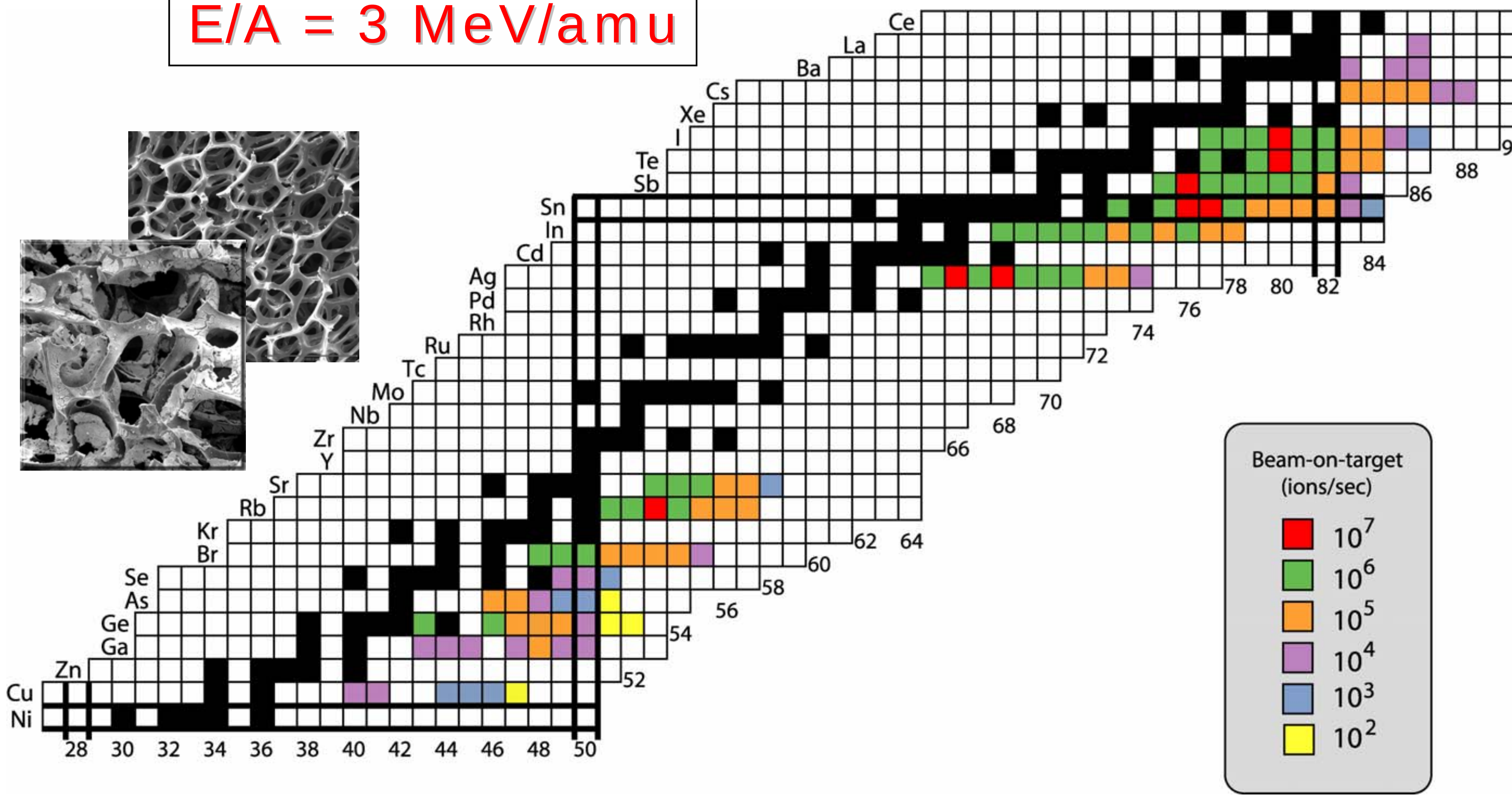
RIB	Energy Range	Highest Intensity	ORIC Current	Purity
	(MeV)	(pps on target)	(μA on target)	(%)
^{7}Be	4 - 100	2.0×10^{7}	n/a	100
^{17}F	10-170	1.0×10^{7}	3	100
^{18}F	10-108	6.0×10^{5}	1.5	100
^{67}Ga	160	2.5×10^{5}	5	> 90
^{69}As	160	2.0×10^{6}	5	~ 10
^{70}As*	140	2.0×10^{3}	0.01	$< 10^{-6}$

*** This beam was used for commissioning of the RIB Injector**

Available Neutron-rich Radioactive Ion Beams

(over 110 beams with intensities ≥10^3 ions/sec)

E/A = 3 MeV/amu



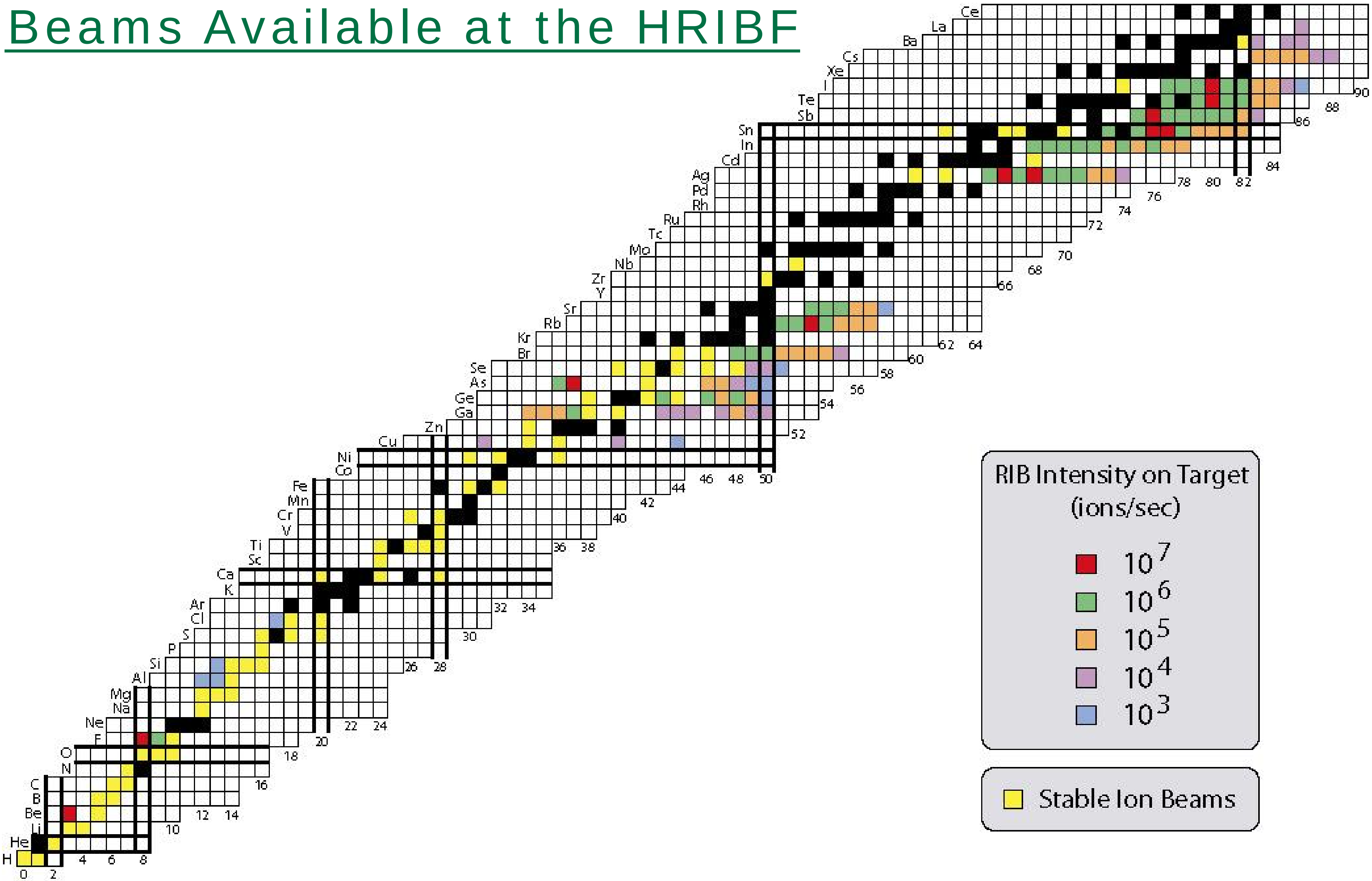
Accelerated n-rich RIBs (A<100 amu)

RIB	Energy Range (MeV)	Highest Intensity (pps)	Purity (%)
^{76}Cu	220	15	0.3
^{77}Cu	220	1.6	0.03
^{78}Cu	220	0.15	0.003
^{79}Cu	220	0.006	0.00012
^{78}Ge	175	1.5×10^6	67
^{80}Ge	179	1.8×10^6	95
^{82}Ge	183 - 327	1.8×10^4	22
^{83}Ge	220 - 327	1500	43
^{84}Ge	220 - 327	95	12
^{85}Ge	220	1.3	18
^{86}Ge	220	0.006	0.8
^{82}Se	380	4.7×10^5	78
^{83}Se	327	1.7×10^5	95
^{84}Se	327 - 380	1.1×10^4	10
^{92}Sr	450	500	72

Accelerated n-rich RIBs (A>100 amu)

RIB	Energy Range (MeV)	Highest Intensity (pps)	Purity (%)
^{117}Ag	460	1.2×10^6	95
^{118}Ag	236 – 455	1.7×10^6	90
^{126}Sn	378	1.0×10^7	50
^{128}Sn	384	3.0×10^6	> 99
^{130}Sn	391 – 550	5.0×10^5	> 99
^{131}Sn	550	2.5×10^5	> 99
^{132}Sn	316	8.6×10^5	96
^{132}Sn	453 – 620	1.5×10^5	96
^{133}Sn	316	1.7×10^4	33
^{134}Sn	316 – 560	2.8×10^3	38
^{136}Sn	400	3	0.2
^{129}Sb	400	2.9×10^7	49
^{132}Te	350 – 396	3.0×10^7	87
^{134}Te	396 – 565	2.4×10^6	95
^{136}Te	396 – 470	5.0×10^5	80

Beams Available at the HRIBF

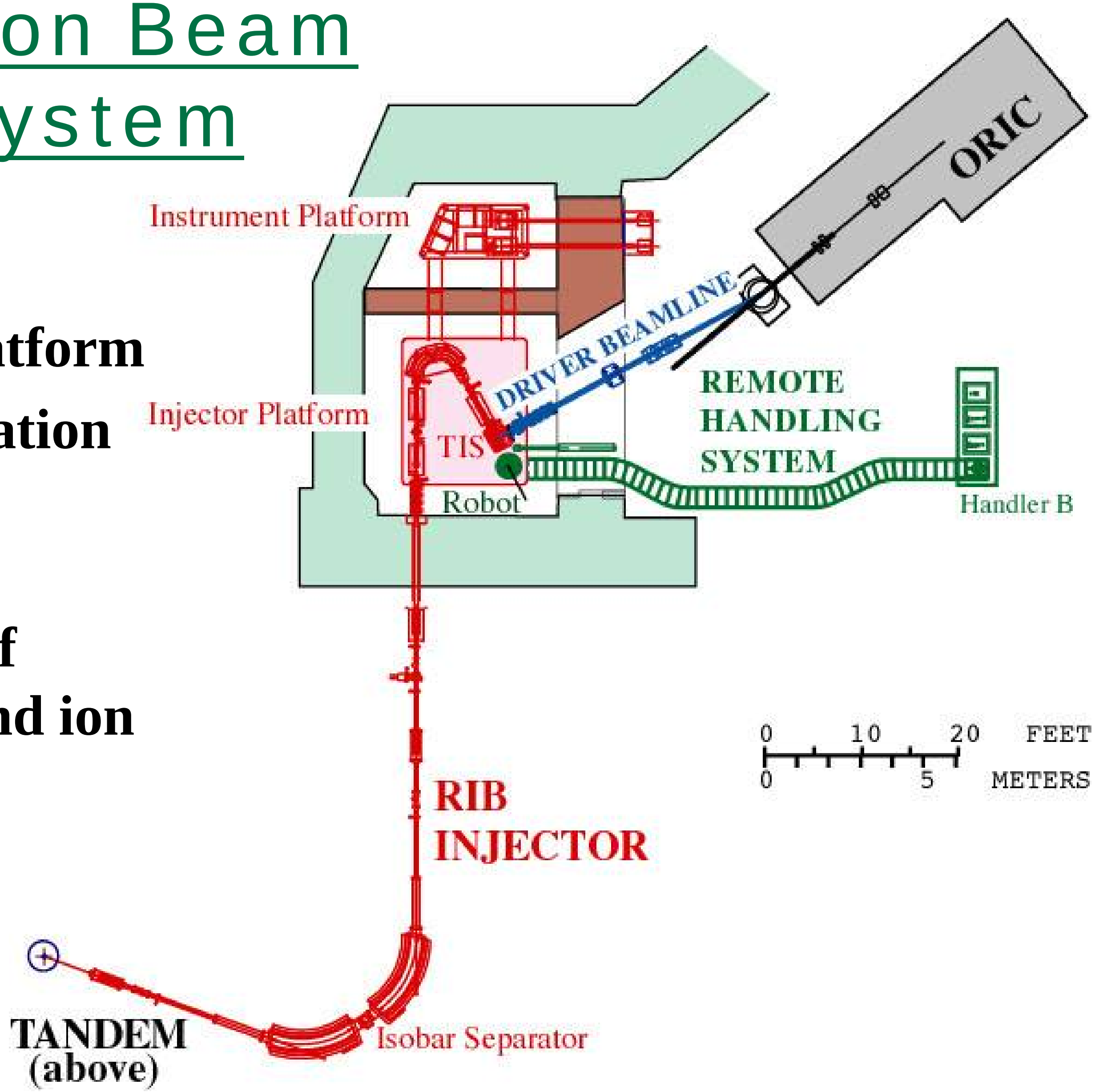


RIB Production Targets

- **HfO_2 fibers** (^{17}F and ^{18}F)
- **Uranium carbide** (n-rich beams via proton-induced fission)
- **Molten metals**
  - Germanium (Ga, As, and Se beams)
  - Nickel (Cu beams)
- **Ni pellets** (^{56}Ni via (p,p2n) reaction – ^{56}Co contamination)
- **Cerium sulfide** (^{33}Cl and ^{34}Cl)
  - Thin layers deposited on W-coated carbon matrix
- **Silicon carbide** (^{25}Al, and ^{26}Al)
  - Fibers (15 μm), powder (1 μm), thin layers on carbon matrix
- **Aluminum oxide** (^{26}Si and ^{27}Si)
  - Thin fibers (6μm) with sulfur added for transport
- **^{7}Be** sputter targets (mixed with copper or niobium powder)

Radioactive Ion Beam Injector System

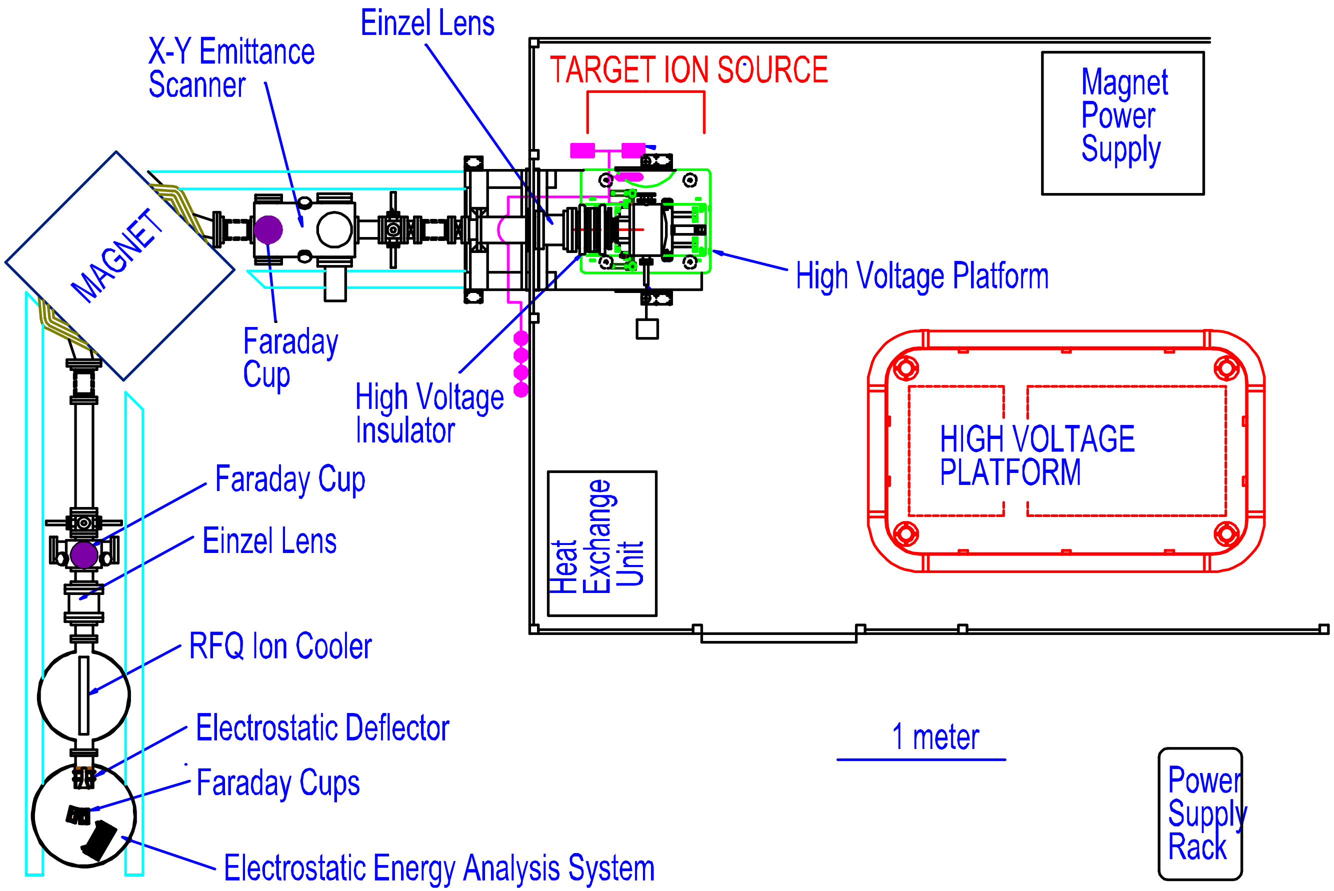
- **300 kV (design) platform**
- **2-stage mass separation**
  - **M/ΔM ~ 1000**
  - **M/ΔM ~ 20000**
- **Robotic handling of activated targets and ion sources**



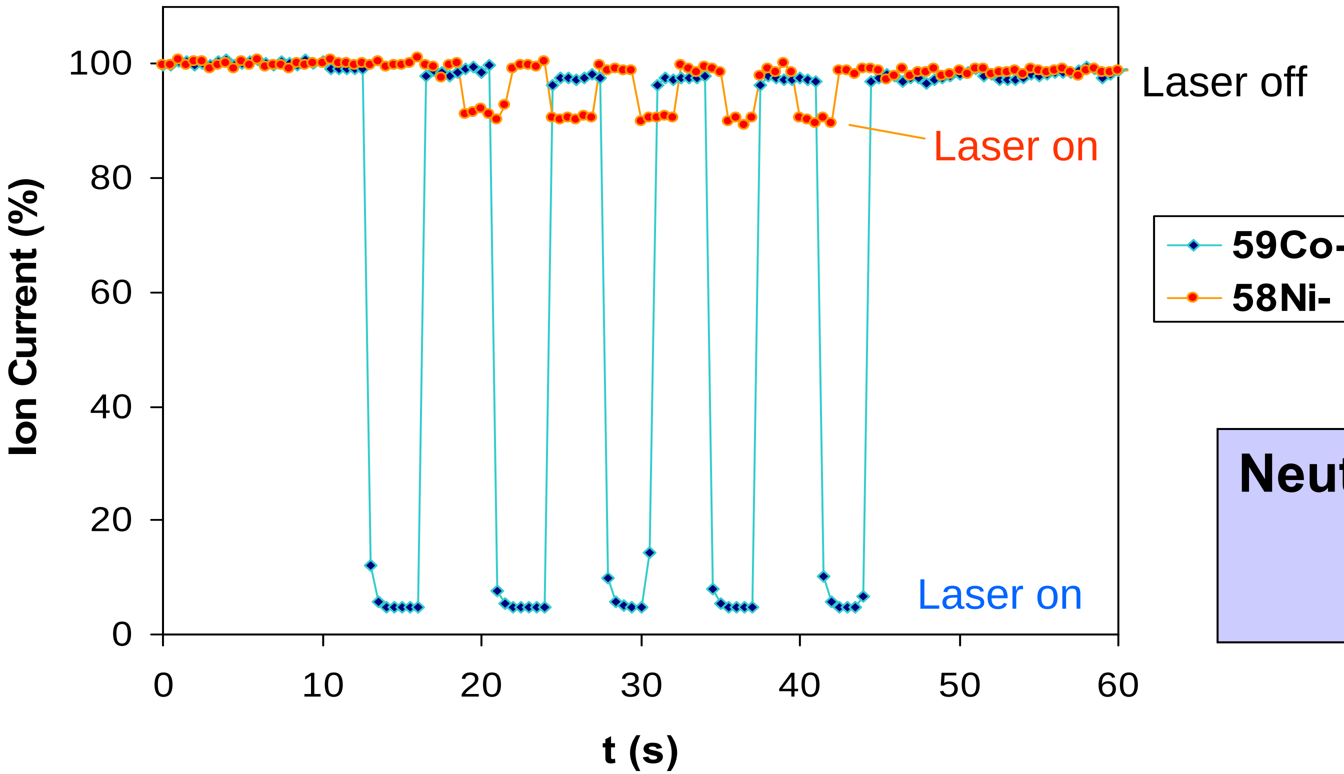
RIB Development and Testing Facilities

- **Ion Source Test Facility I (ISTF-1)**
  - characterize ion sources (efficiency, longevity, emittance, energy spread, effusion)
  - some target tests (e.g. effusion through matrix)
  - ion cooler for negative ions (gas-filled RFQ)
- **Ion Source Test Facility II (ISTF-2)**
  - laser ion source
  - ECR ion source
- **On-Line Test Facility (OLTF)**
  - low intensity tests of target and ion source performance
  - compatible with the RIB Injector and results are scaleable
- **High Power Target Laboratory (HPTL)**
  - NOW available for target tests using high power beams from ORIC

Ion Source Test Facility I (ISTF-1)



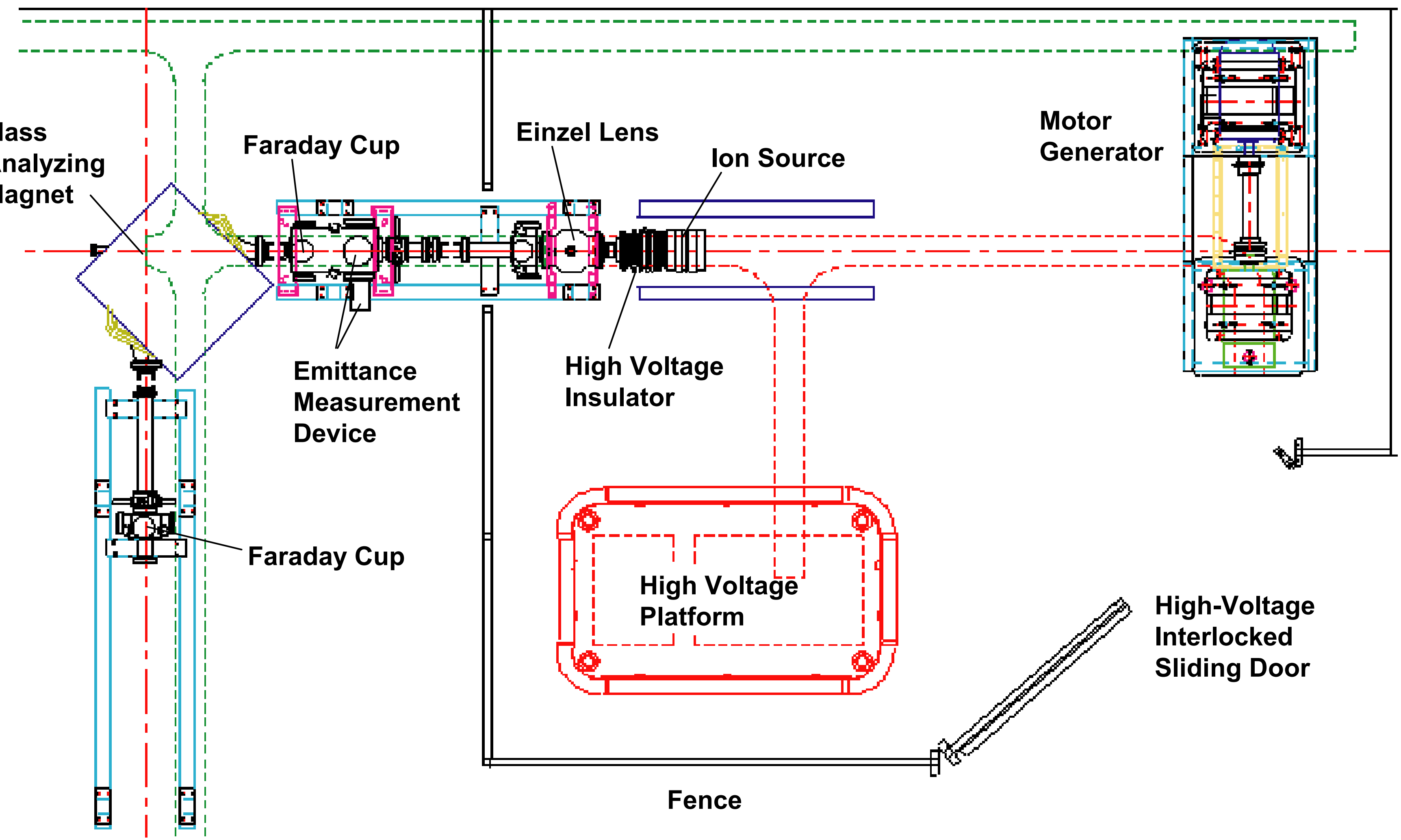
Laser-induced Photodetachment of Ni^- and Co^- in a He-filled RFQ Ion Cooler



Neutralization:
Co^-: ~95%
Ni^-: ~10%

- Laser: Nd:YAG, 5 W, CW, 1064 nm
- About 50% of laser beam passed through the RFQ (40 cm long)
- The energy of the negative ions was reduced from 5 keV to <50 eV in the cooler
- Laser interaction time in the RFQ cooler is on the order of 1 ms

Ion Source Test Facility II (ISTF-2)



Laser Ion Source Experiments (8/31/04 – 9/23/04)

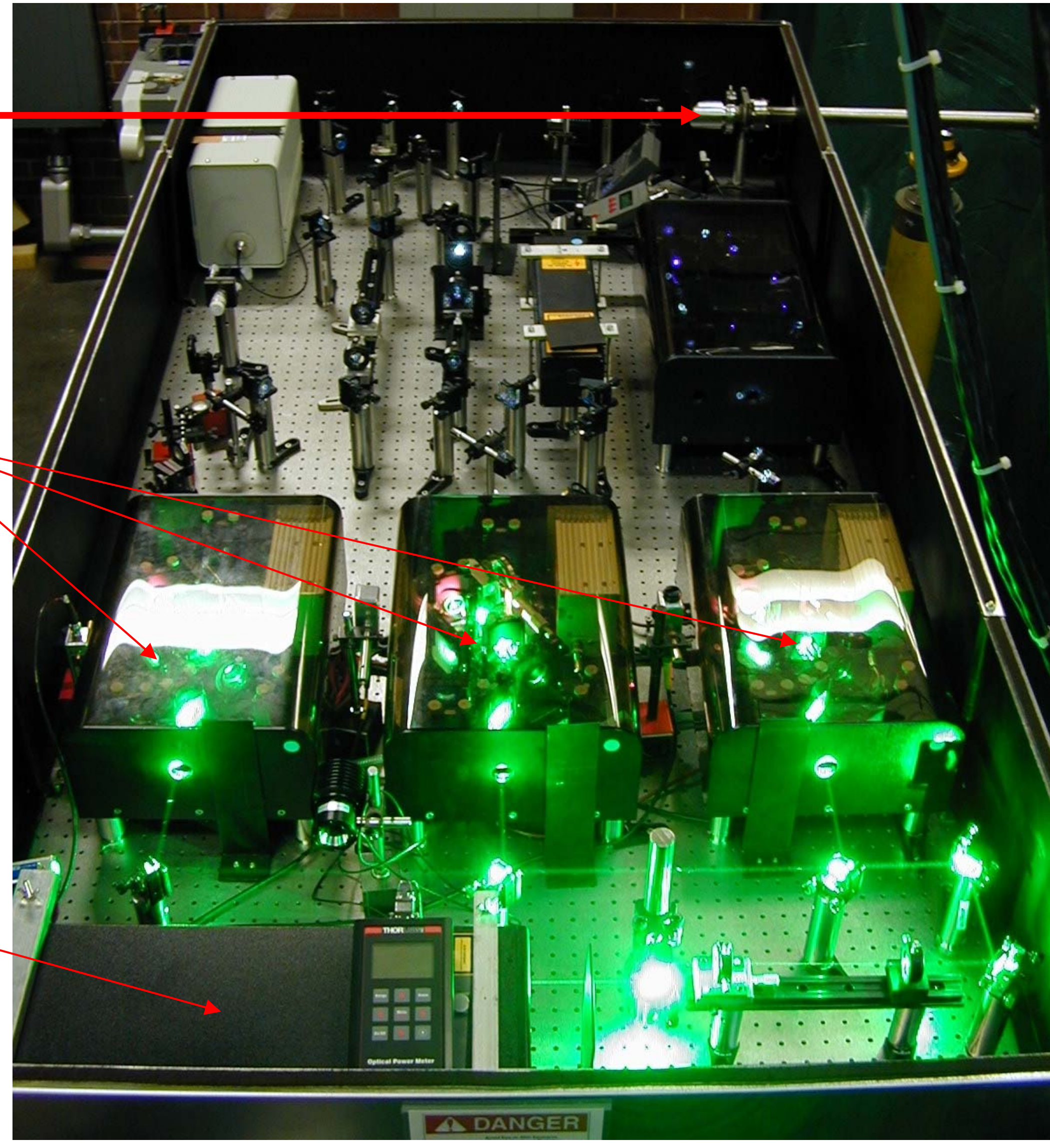
- Laser ion source set up and operated at HRIBF in collaboration with a group from Mainz (Klaus Wendt and students)
- Three-step ionization of Sn, Ge, and Ni obtained
- Last ionization step:
  - autoionization state for Sn and Ge
- No surface ionized Sn, Ge, and Ni ions observed
  - hot-cavity temperatures ~ 1700-2000 C
- Overall LIS efficiencies:
  - 22% for Sn (compared to 10% achieved at ISOLDE)
  - 3.3% for Ge
  - 2.7% for Ni

Laser setup for the initial test at the HRIBF

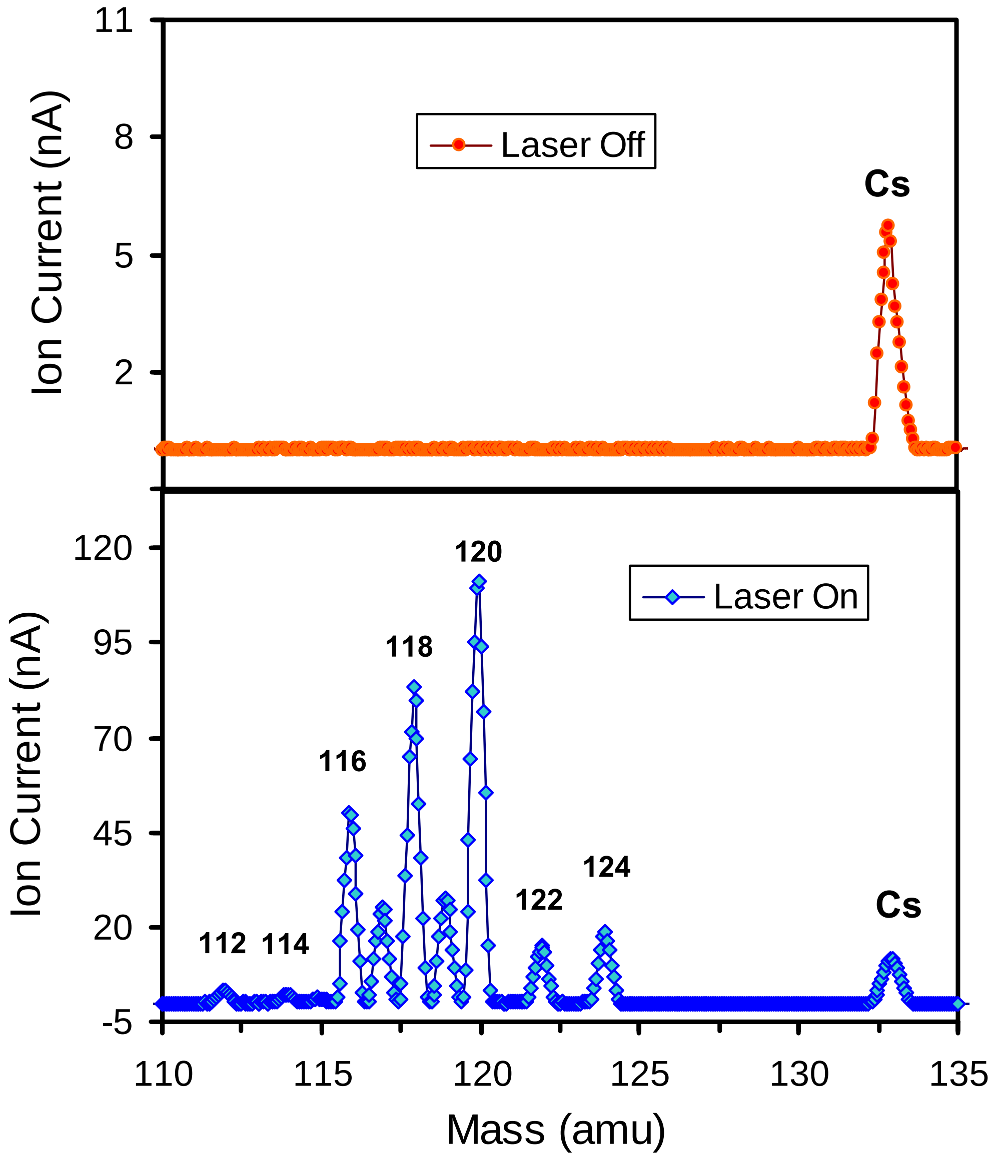
Laser beam into the hot cavity through the mass-analysis magnet

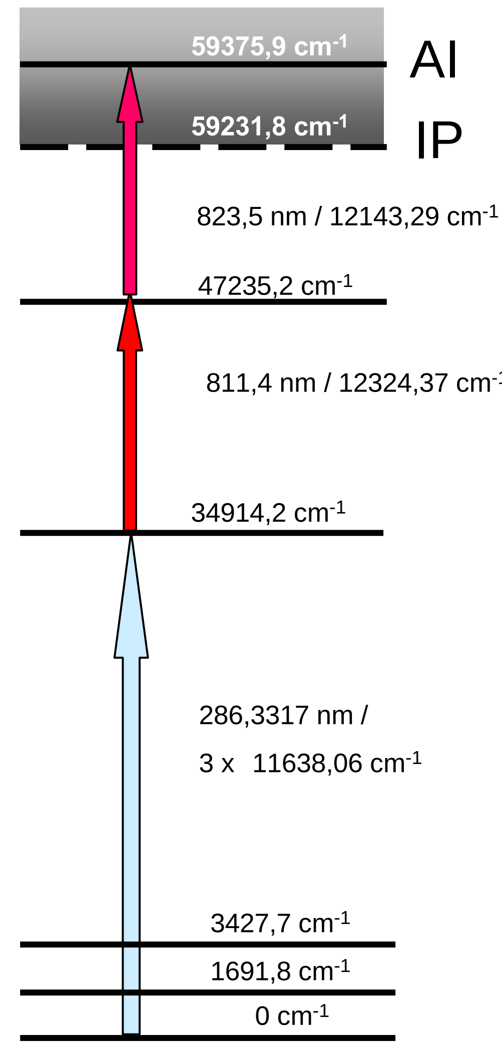
Ti:sapphire lasers (supplied by the Mainz group)

Nd:YAG Pump laser (60 W, 10 kHZ, 532 nm)

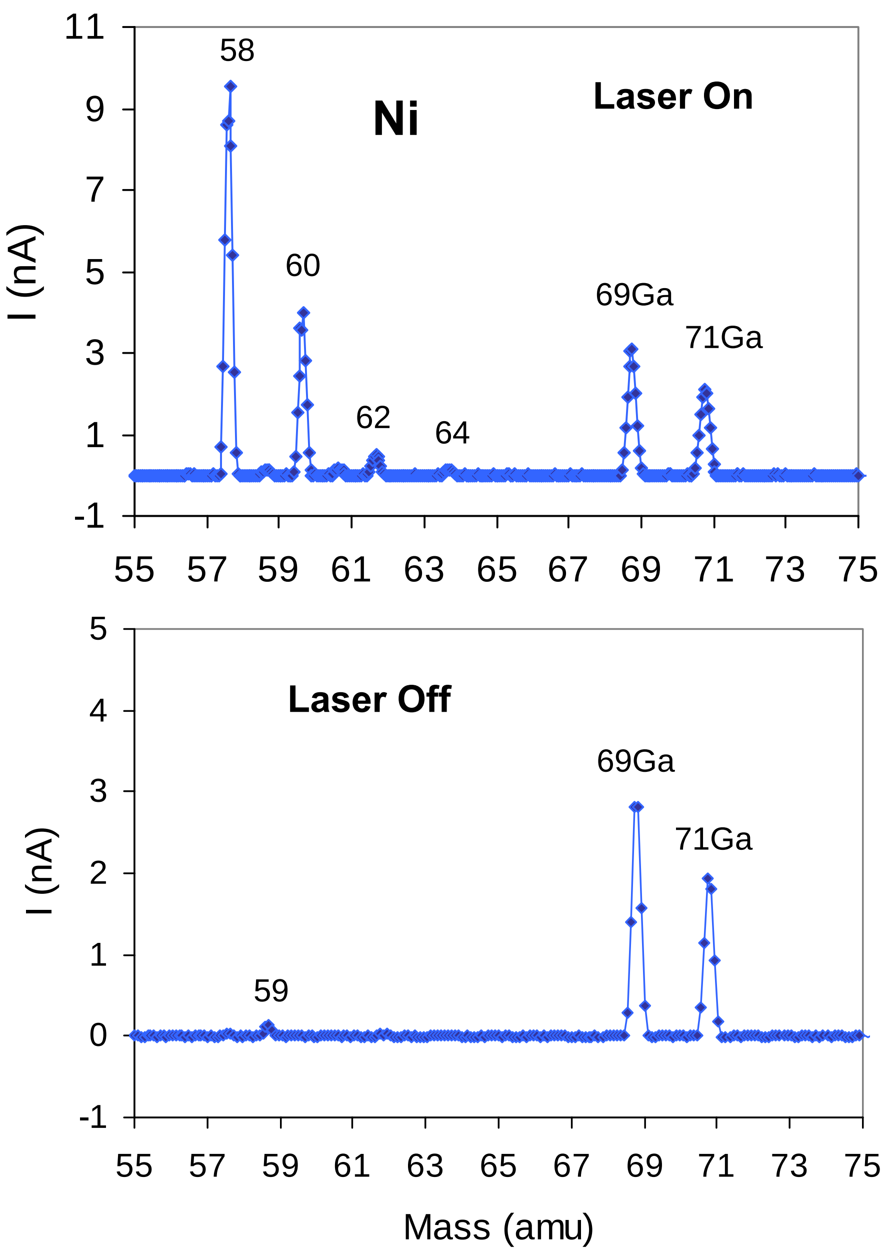


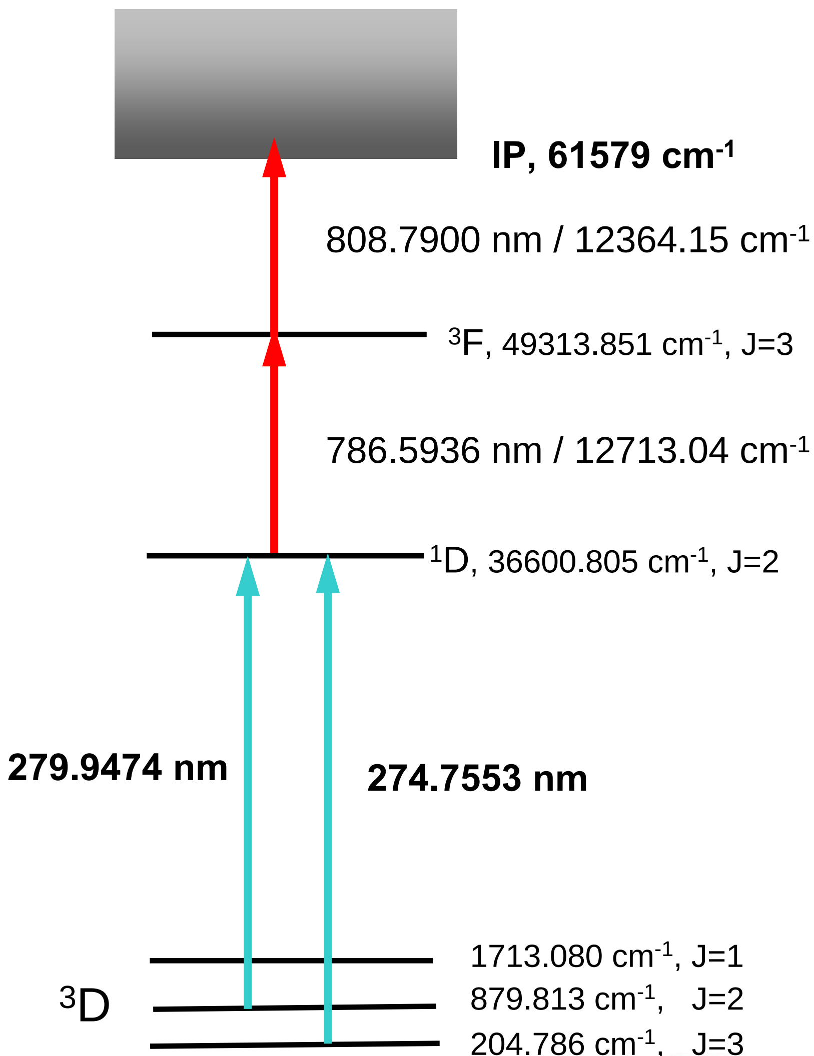
Sn Ionization Scheme



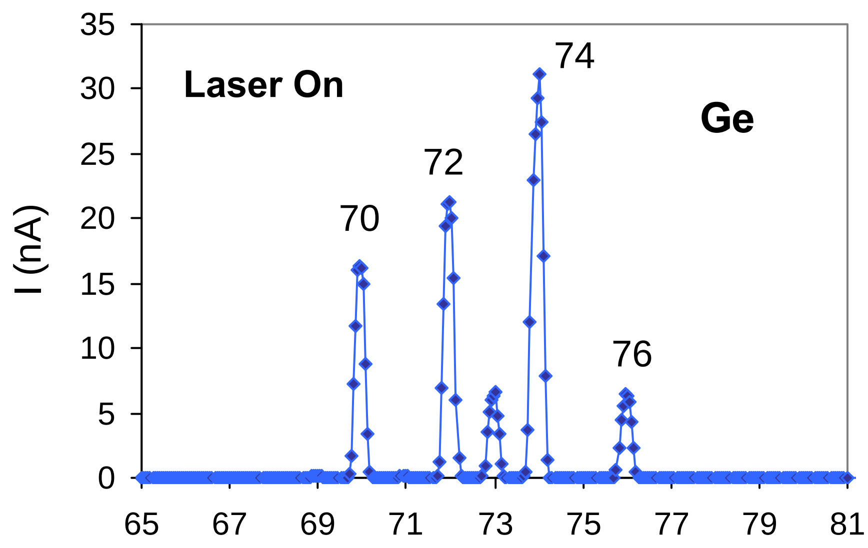


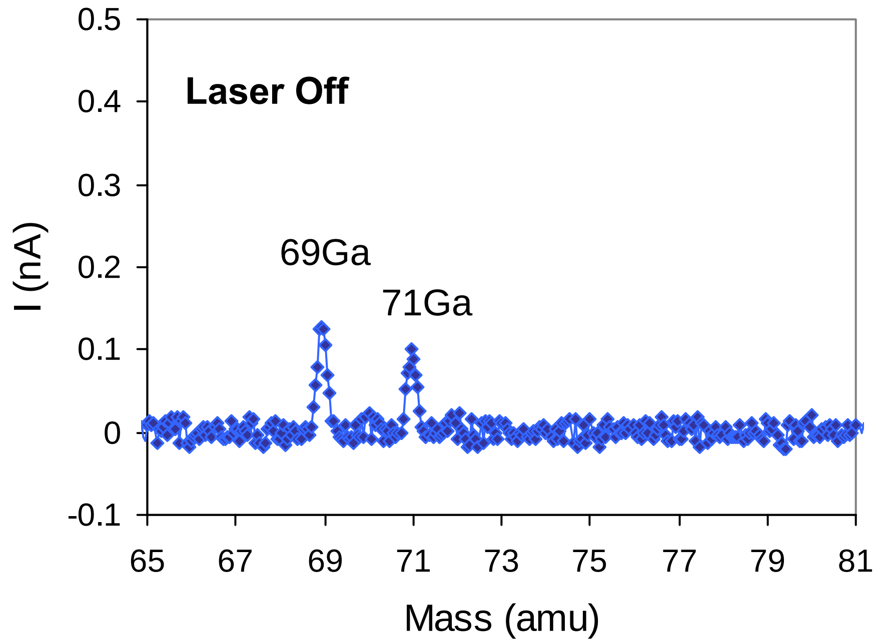
Ni Ionization Scheme

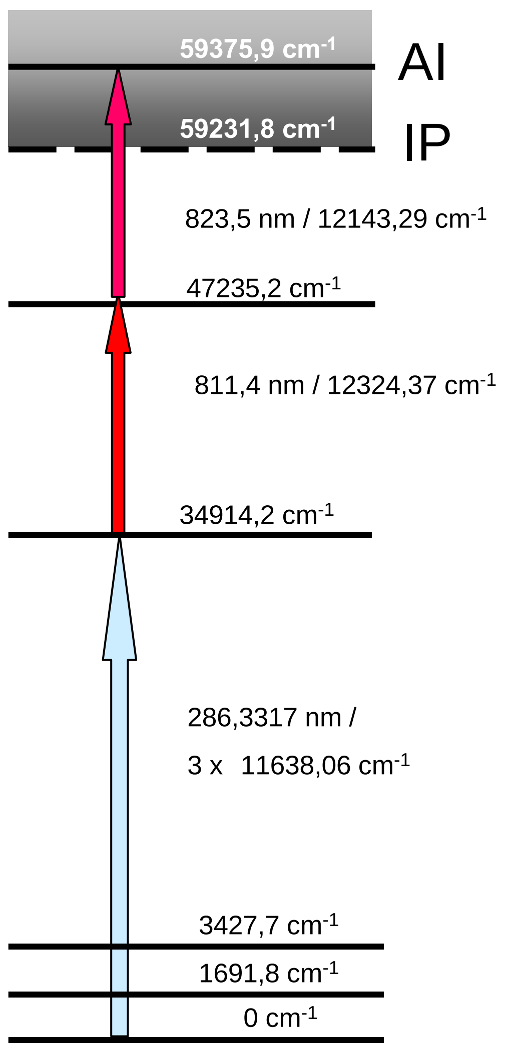




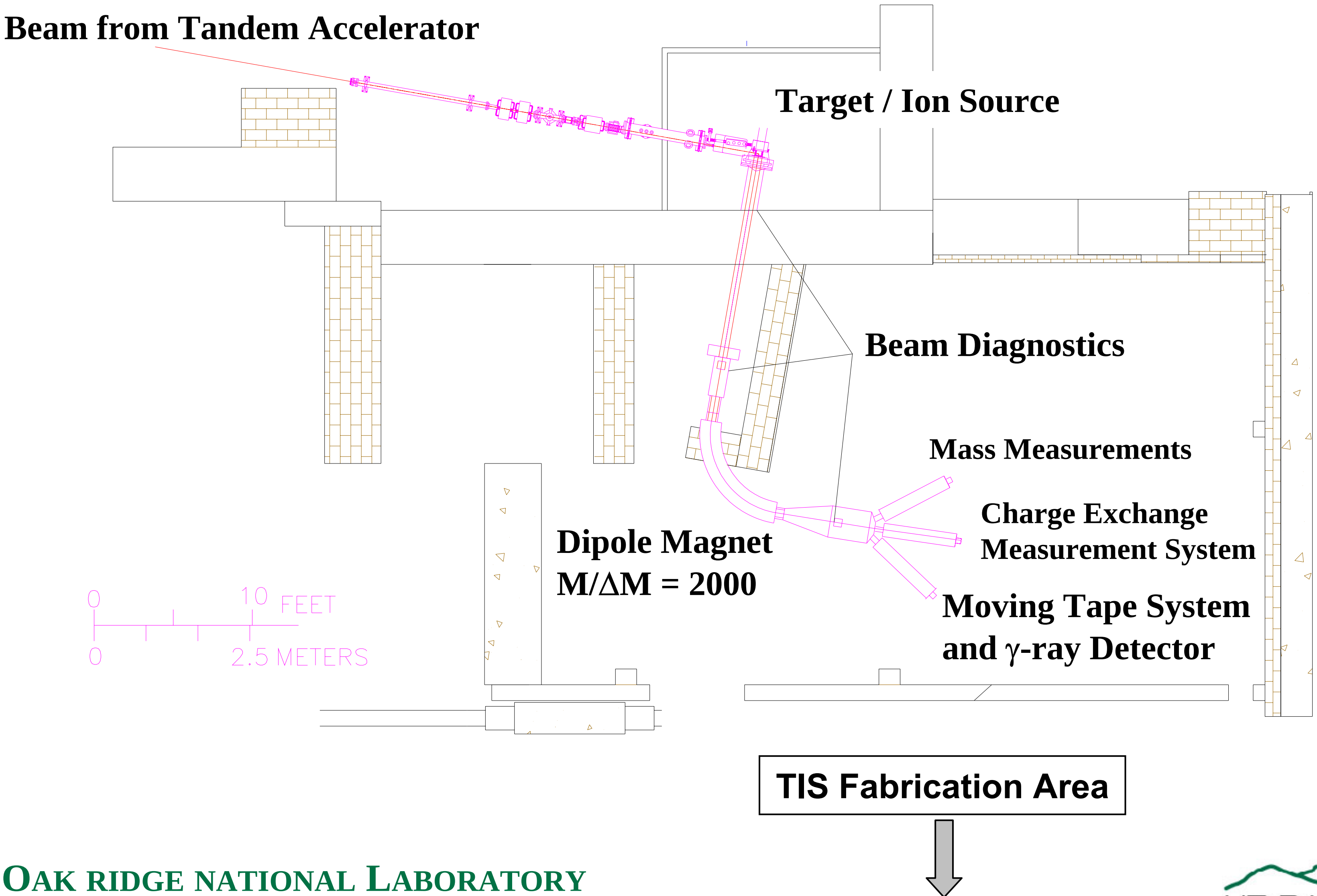
Ge Ionization Scheme





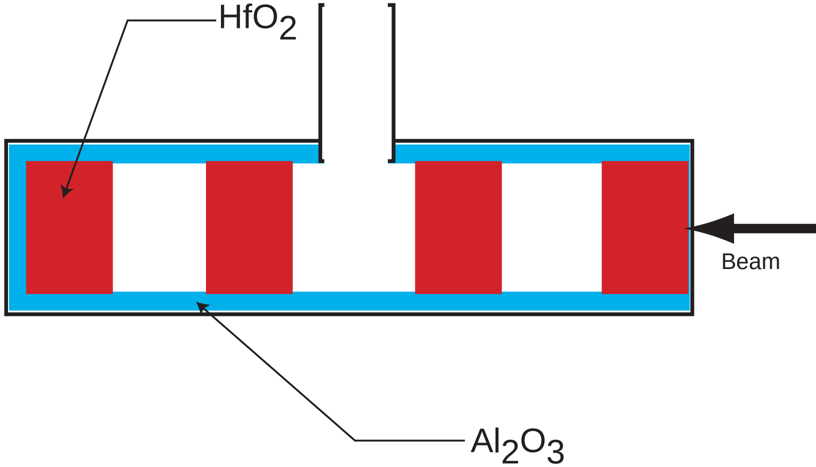


On-Line Target and Ion Source Testing Facility

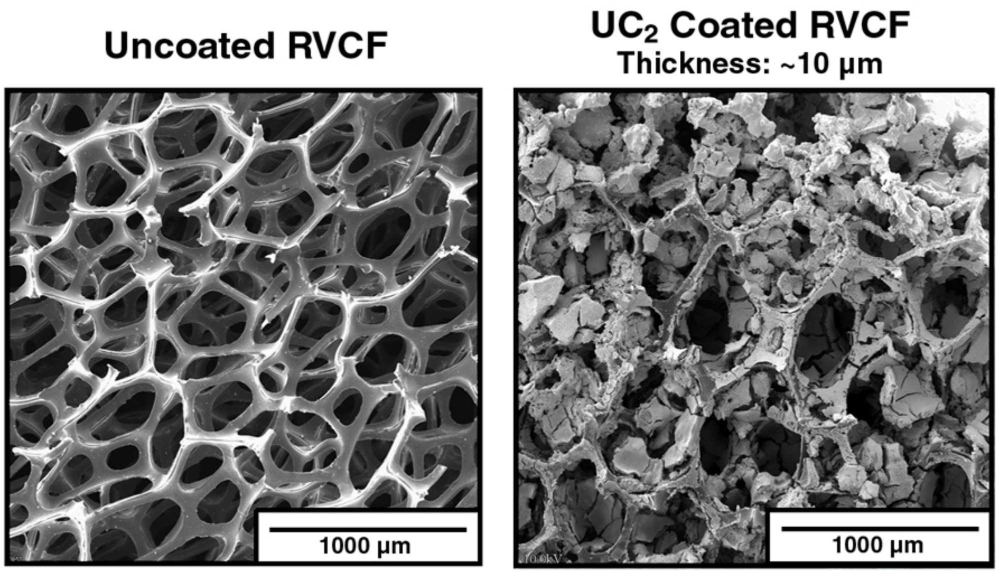


HfO_2 Fiber Target for Production of $^{17,18}F$ Beams

- **Thin Fibers (5 μm) - fast diffusion**
- **High porosity (density is 1.15 g/cm^3)**
- **Refractory (m.p. is 2770 C)**
- **Free of volatile impurities**
- **4 rolls of HfO_2 cloth used for target**
  - **1.5 cm diameter x 1 cm thick each**
- **Al_2O_3 felt sheath**
  - **Provides aluminum vapor**
  - **Fluorine is transported as AlF molecule**
- **HfO_2 cloth sheath**
  - **Keeps alumina away from the Ta wall**



UC Targets for Production of Neutron-rich Beams



- **RVC fiber diameter: 60 μm**
- **Matrix density: 0.06 g/cm^3**
- **UC coating thickness: 8 - 10 μm**
- **Target density: 1.2 g/cm^3**
- **Long useful lifetimes**
  - **(>50 days with 10 μA on target)**

SiC targets (for the production of ^{25}Al and ^{26}Al beams)

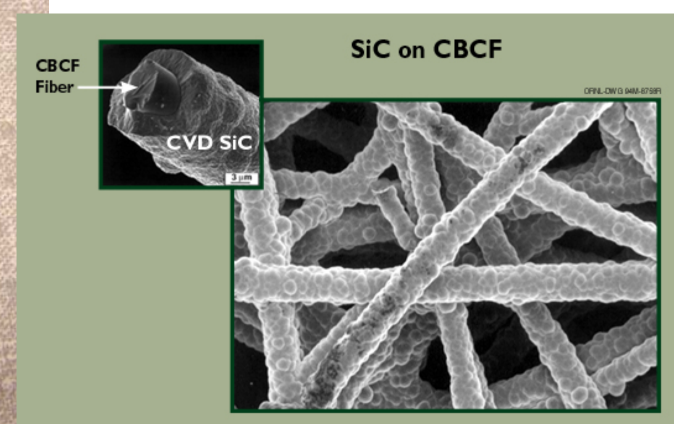
- 15 μm diameter SiC fibers
- 1 μm diameter SiC powder
- SiC does not sinter
- Maximum operating temperature is 1650 C
- ^{25}Al yields were about the same – 10^4 ions/sec/μA
- Can increase yield significantly (x10) by adding fluorine to system and extract as AlF
- Next target is a thin layer of SiC on a graphite matrix

$$^{28}Si(p,\alpha)^{25}Al$$

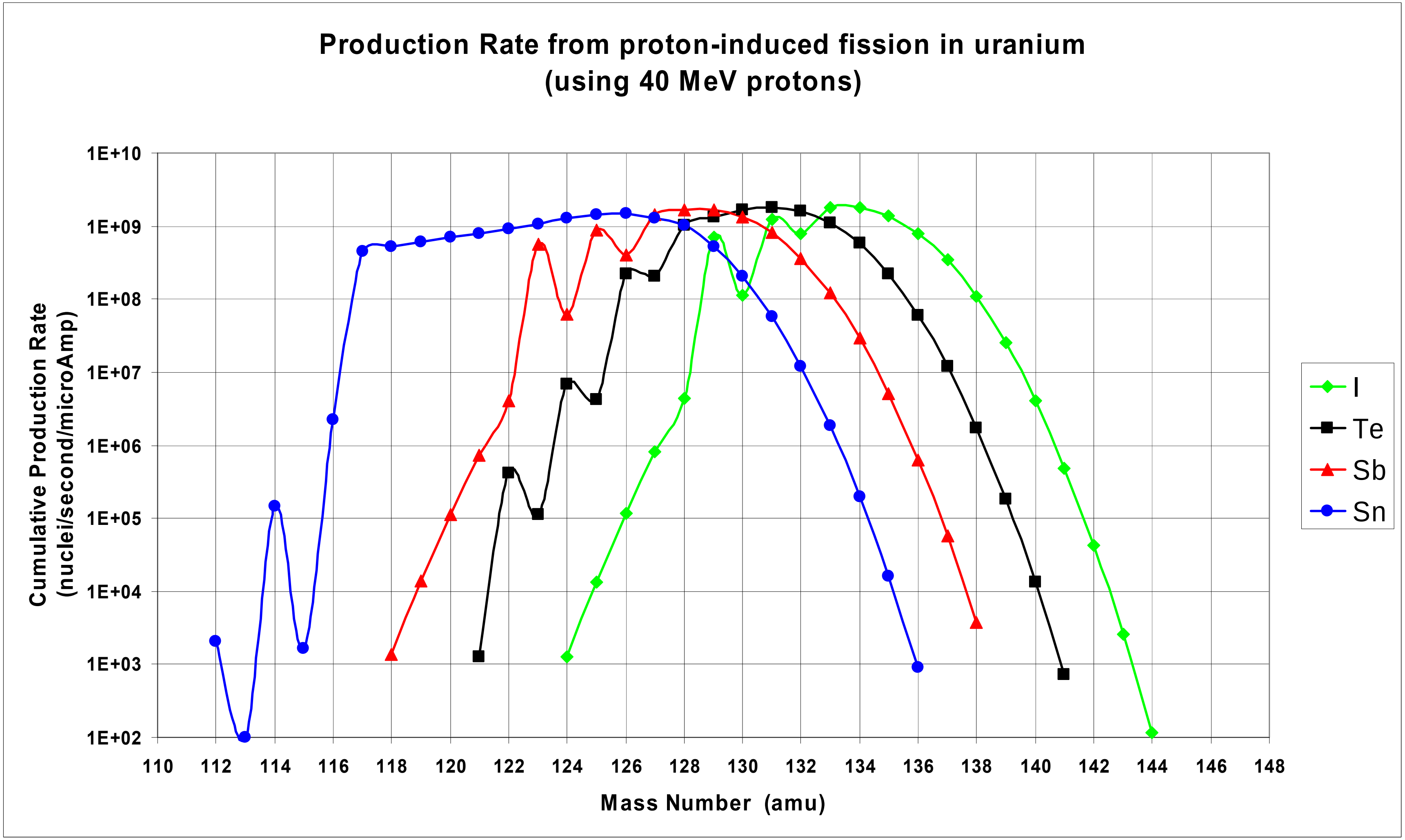
$$^{28}Si(d,\alpha n)^{25}Al$$

$$^{28}Si(p,2pn)^{26}Al$$

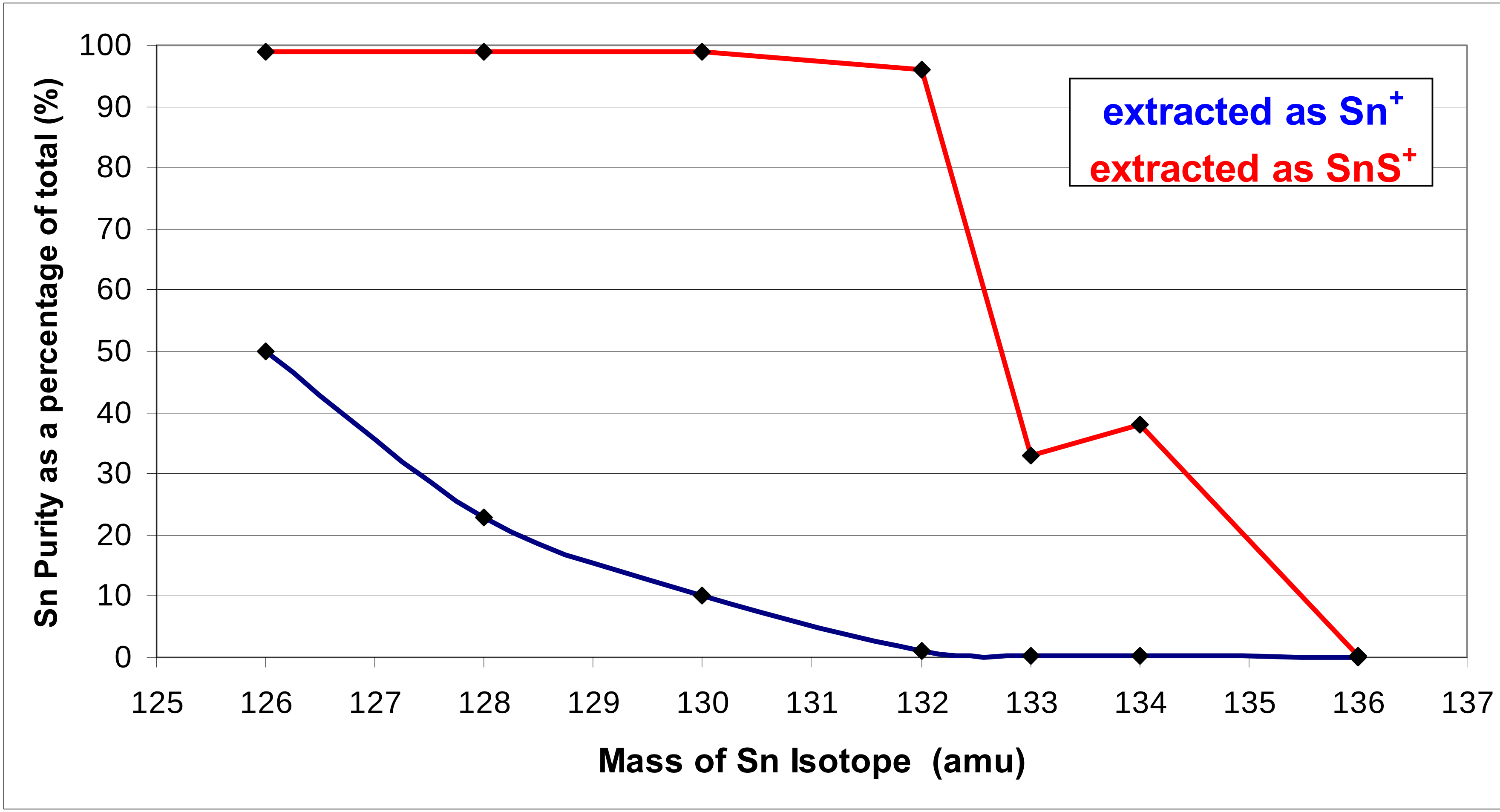
$$^{28}Si(d,\alpha)^{26}Al$$



Production Rates for Sn, Sb, Te, and I isotopes in a UC target

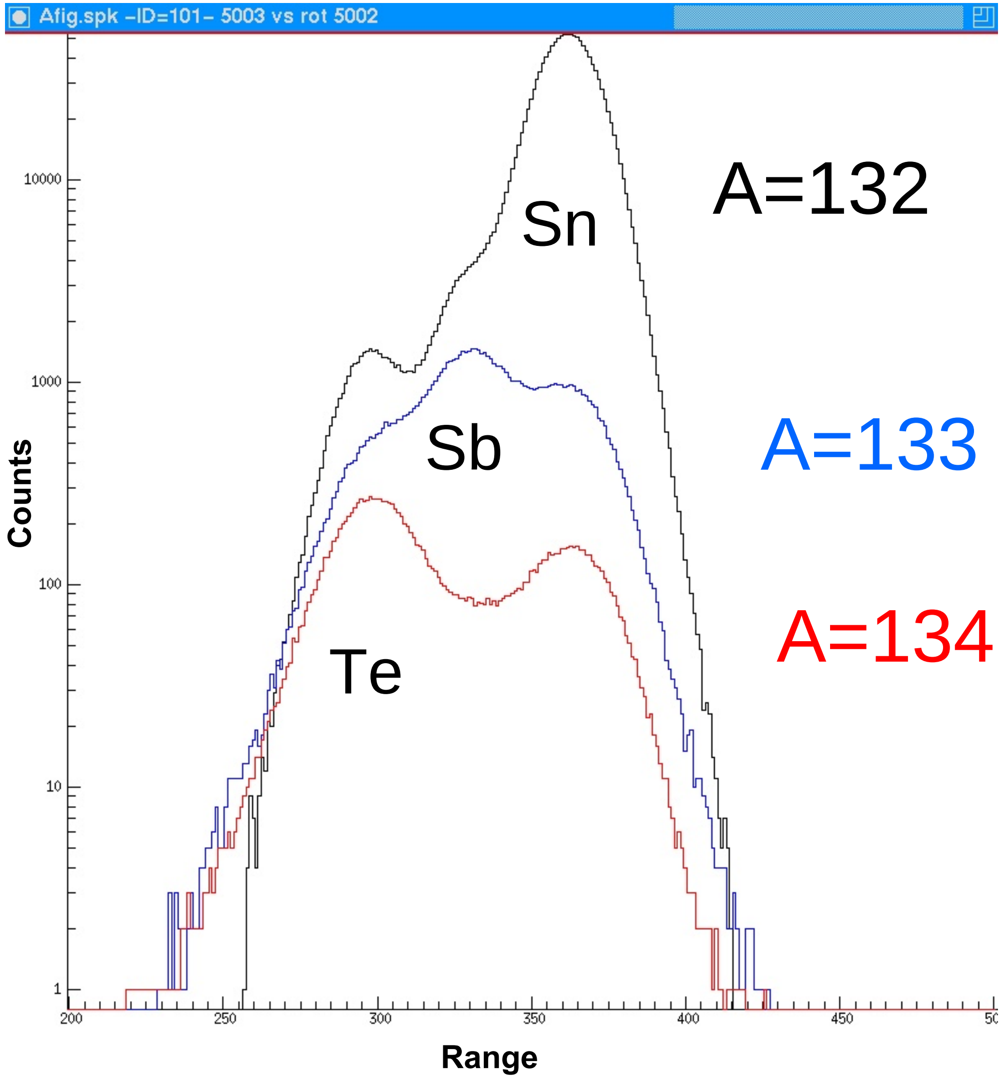


Purity of radioactive Sn Beams

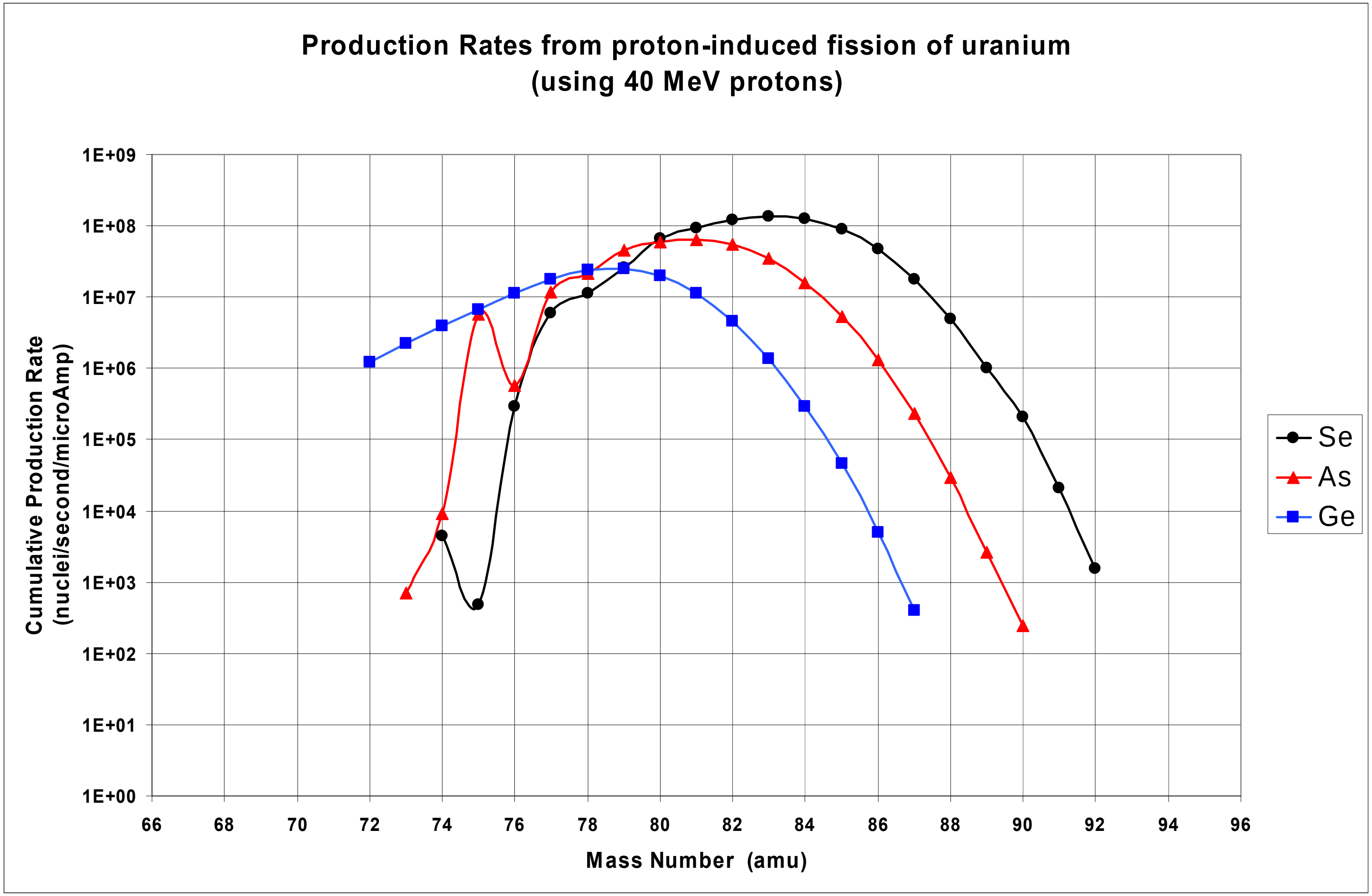


Intensities for Sn, Sb, and Te Isotopes

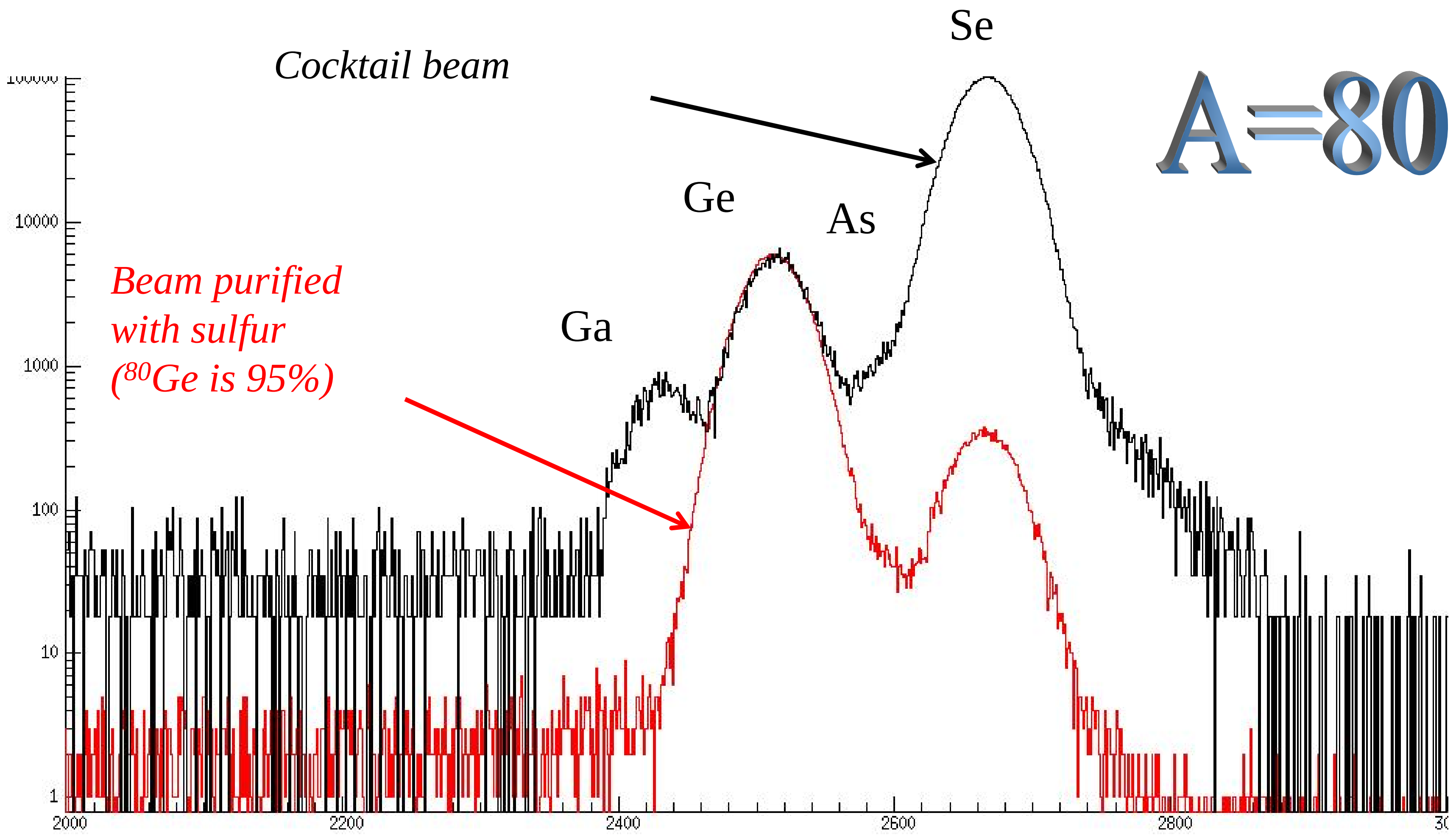
- **Measured with Bragg detector (gas chamber)**
- **Beam energy is 316 MeV**
- **^{132}Sn beam intensity is 8.6×10^5 pps (96% of total)**
- **^{133}Sn beam intensity is 1.5×10^4 pps (33% of total)**
- **^{134}Sn beam intensity is 2.8×10^3 pps (38% of total)**
- **These beams were extracted as sulfide molecules from the ion source**
- **The percentages of Sn in the atomic ion beams are <1%**
- **The ^{134}Sb/^{133}Sb ratio is small due to a much shorter half-life**



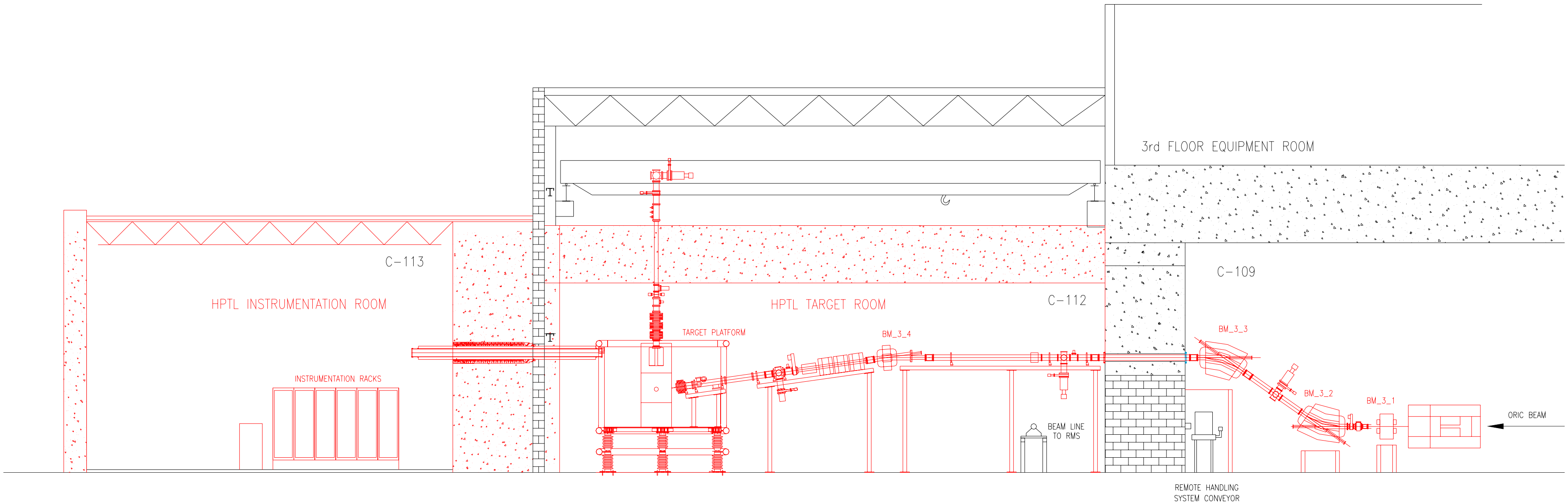
Production Rates for Ge, As, and Se isotopes in a UC target



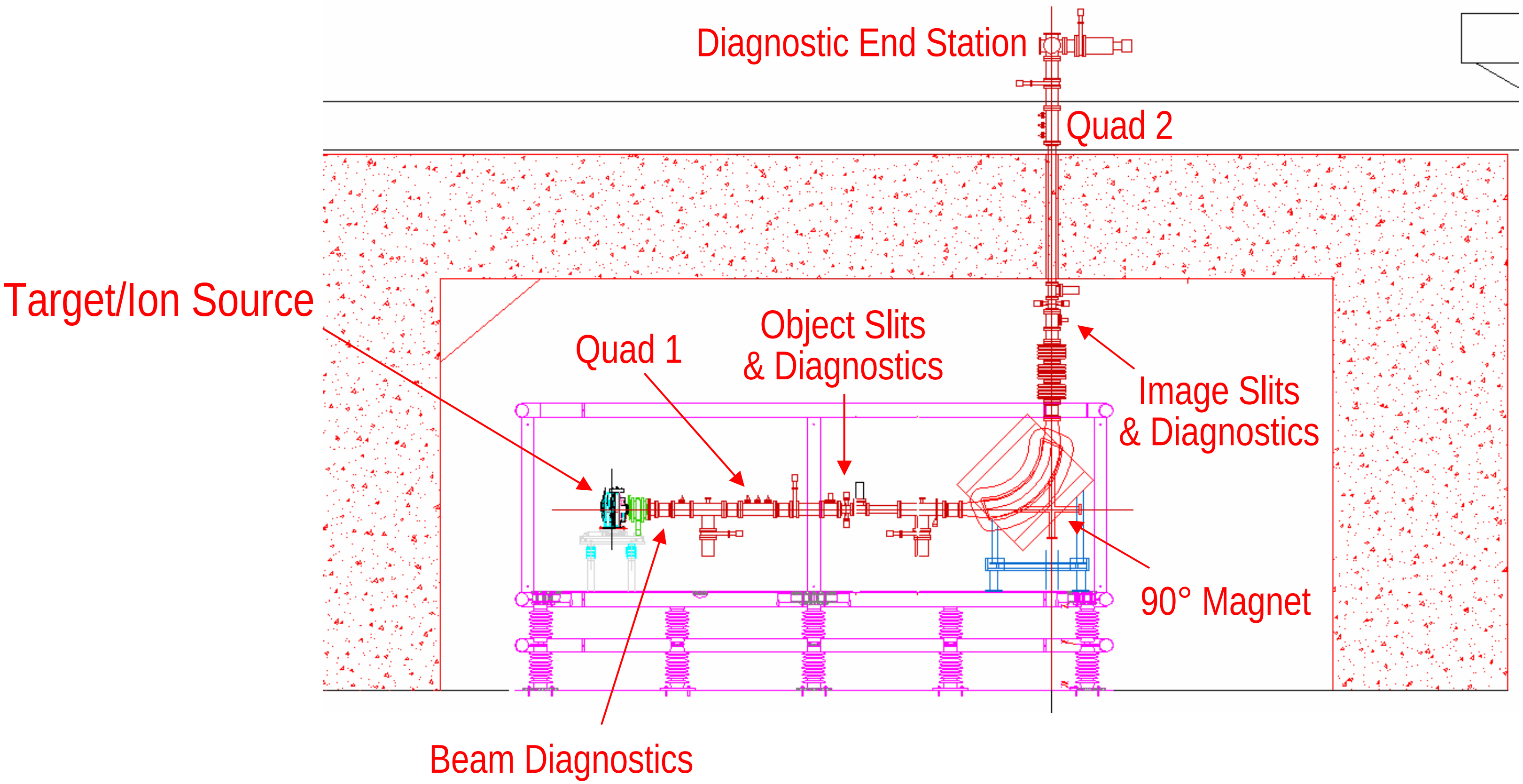
Purification of ^{80}Ge beam



Elevation View of HPTL



RIB Analysis Beam Line



Ion Sources at the HPTL

- **The target station and the RIB analysis beam line are designed to be flexible enough to accommodate a variety of ion sources**
  - **Electron-Beam Plasma ion source (EBPIS)**
  - **Kinetic Ejection Negative ion source (KENIS)**
  - **Laser ion source (LIS)**
  - **Positive surface ionization sources (hot Ta or W tubular ionizer)**
  - **Negative surface ionization sources (e.g. LaB_6 ionizer)**
  - **Cs-sputter type ion sources (multi-sample, batch-mode)**
  - **Close-coupled designs (e.g. FEBIAD ion source – GSI design)**
  - **Electron Cyclotron Resonance (ECR) ion sources**
  - **Ion guide (cooler) techniques**

Plans for Target Development at the HPTL

- **Materials tests with high power (54 MeV protons, up to 20 μA)**
  - SiC, M_5Si_3 (M = Zr, Ta, W, Nb, …) for ^{25}Al and ^{26m}Al beams
  - CeS for ^{33}Cl and ^{34}Cl beams
- **UC target tests**
  - Proton-induced fission vs. deuteron-induced fission (direct)
  - Investigate 2-step targets (larger volumes)
  - Higher density UC targets
    - Measure release efficiency for short-lived isotopes
    - Lifetime of target with high power density
- **Thin target geometries**
  - Liquid targets
    - As and Se from liquid germanium
    - Cu from liquid nickel
  - Irradiation with ^3He and ^4He beams ($Al_2O_3 \rightarrow$ P, SiC $\rightarrow$ S, C $\rightarrow$ ^{15}O)
- **Production beam manipulation (rastering)**
  - HfO_2 target for increased ^{17}F beam intensity
- **Ion sources**
  - LaB_6 ion source to make pure Br and I beams (investigate long-term poisoning with high intensity production beams)
  - Close-coupled target to reduce effusion times