From New Actinide Target Technology to Heavy Element Chemistry

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Acknowledgements

Overview

- The Need for New Target Technology
  - Overview of Target Methodologies
  - Polymer-Assisted Deposition
  - Electrochemical Molecular Deposition of ^{242}Pu
- The First Direct Verification of Element 114
- A new A and Z measuring facility at the BGS

The Need For New Target Technology

- Upcoming new, higher beam intensities will require targets that can withstand substantially higher heat loads
- LBNL's superconducting AECR source will soon provide beams with substantially higher intensities
  - this is a current trend world wide
  - ^{48}Ca beams with 2 pμA will be delivered at LBNL
- Currently available targets may be unable to properly perform under these conditions
  - molecular plated targets will definitely not be adequate
    - flaking and pin hole development threatens accellerators and separators

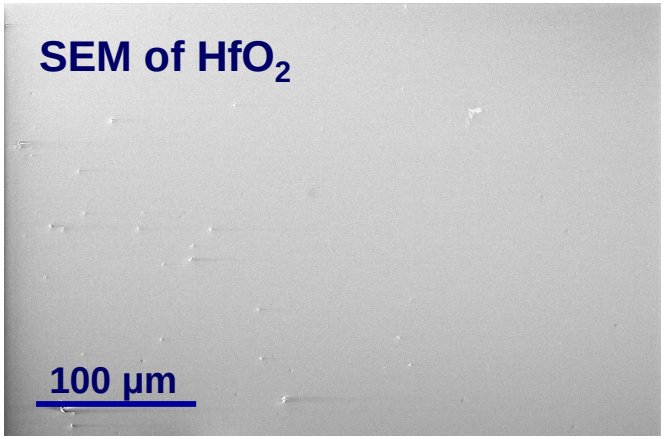
Overview of Target Preparation Methods

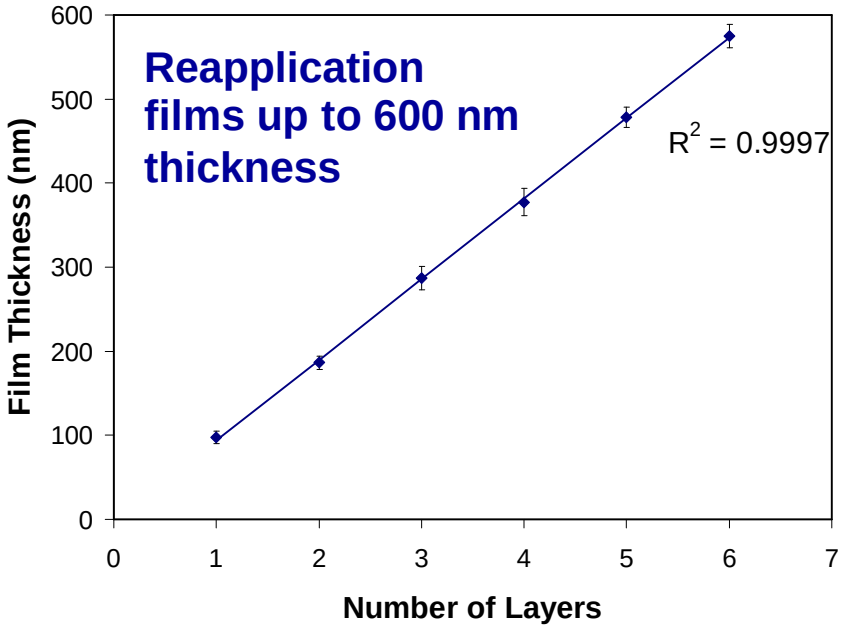
	Target Thicknesses	Homogeneity	Efficiency	Contamination
Molecular Plating / Electro-deposition[1]	0.1-2 mg/cm^2	Granular growth at 1-3 mg/cm^2	20-90%	Minimal
Vacuum Deposition[1]	Thin targets	Homogeneous	1% for a 1mm circular target	Significant
Painting[1]	Up to 8 mg/cm^2	Homogeneous	>90%	Minimal

[1] Glover *et al., Nuclear Instruments and Methods* **102**, 443–450 (1972)

Nuclear Targets by Polymer-Assisted Deposition (PAD)

- Spin coating of metals chelated to a multi-dentate aqueous polymer (polyethylenimine (PEI))
- Annealing of spin-coated films yields a crack-free, uniform and homogenous metal oxide film
- PAD reapplication can produce film of desired thickness

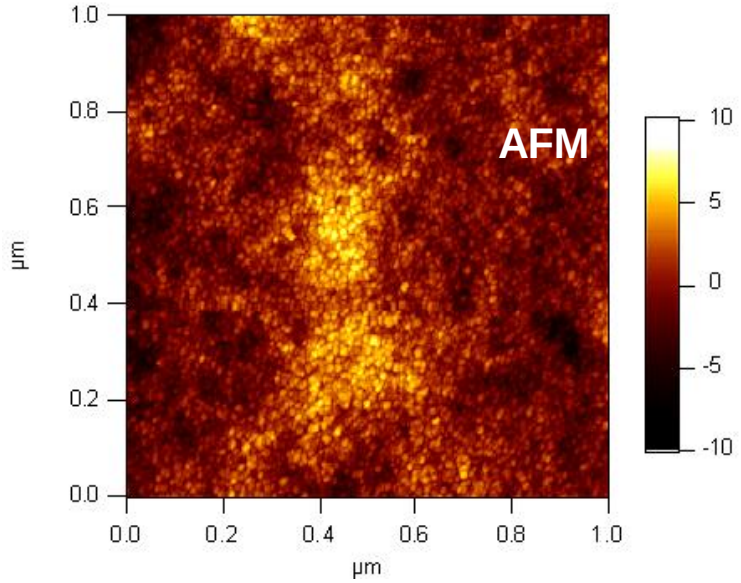




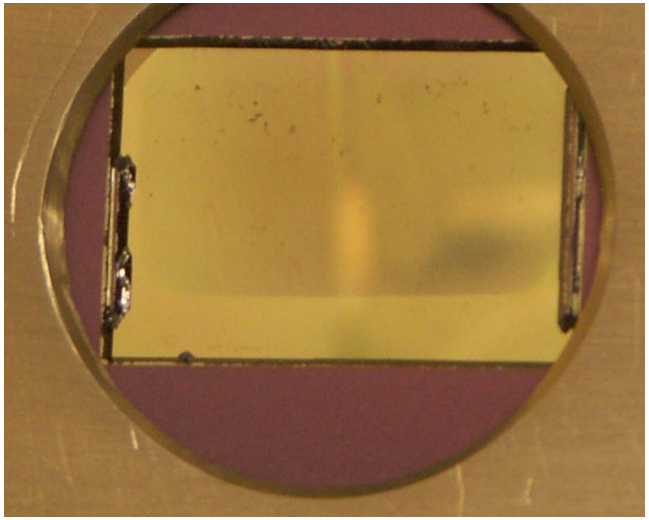
M. Garcia, M. Ali, T. Parsons-Moss, P. Ashby, H. Nitsche,Thin Solid Films, 2008

Stability of PAD-prepared Nuclear Targets

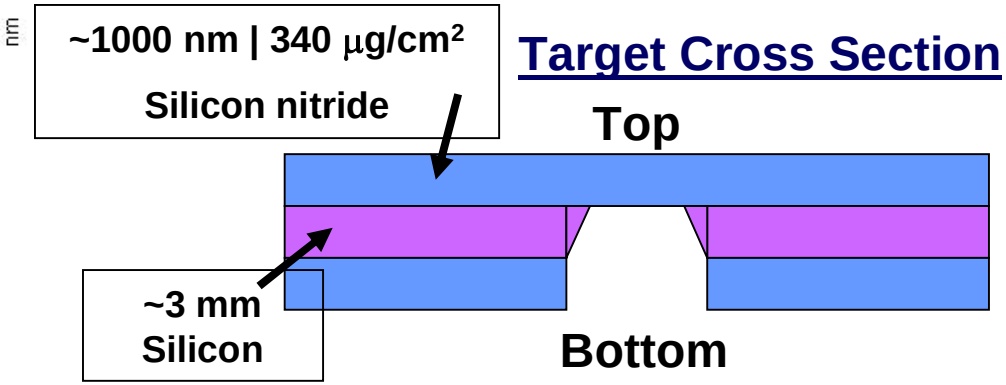
- **Targets were tested with heavy-ion irradiation (^{40}Ar, 1.3 x 10^{15} particles). Surface homogeneity only changed by a few nanometers as determined by Atomic Force Microscopy (AFM).**



Thulium(III) Oxide Target (250 µg/cm²)

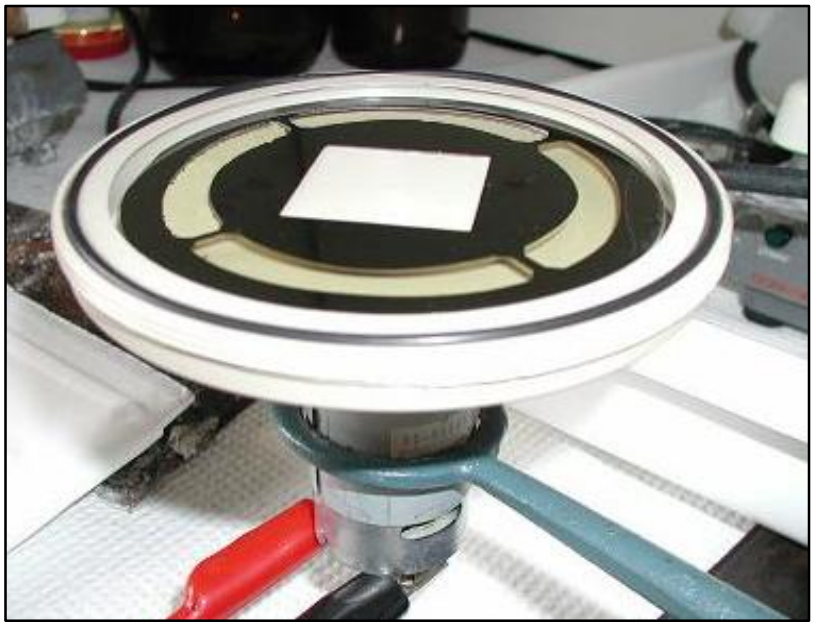


Target Cross Section

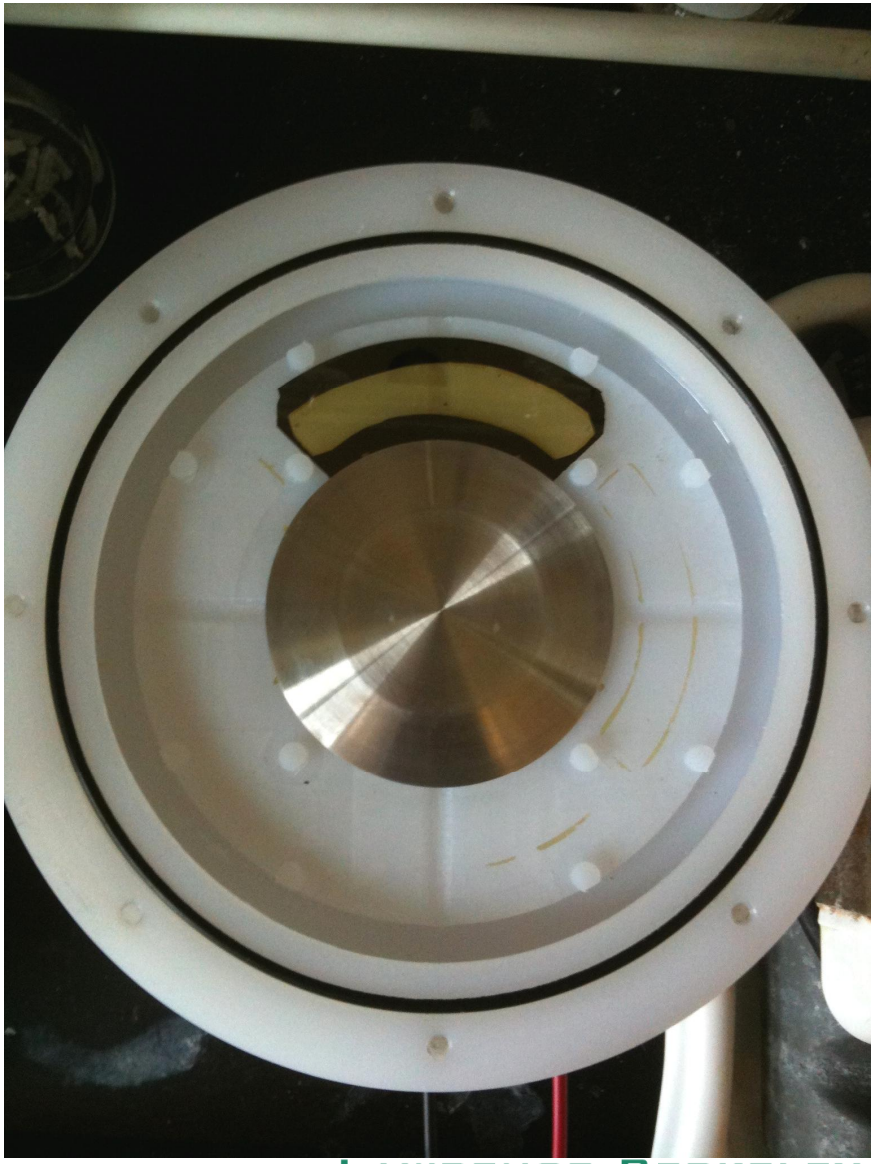


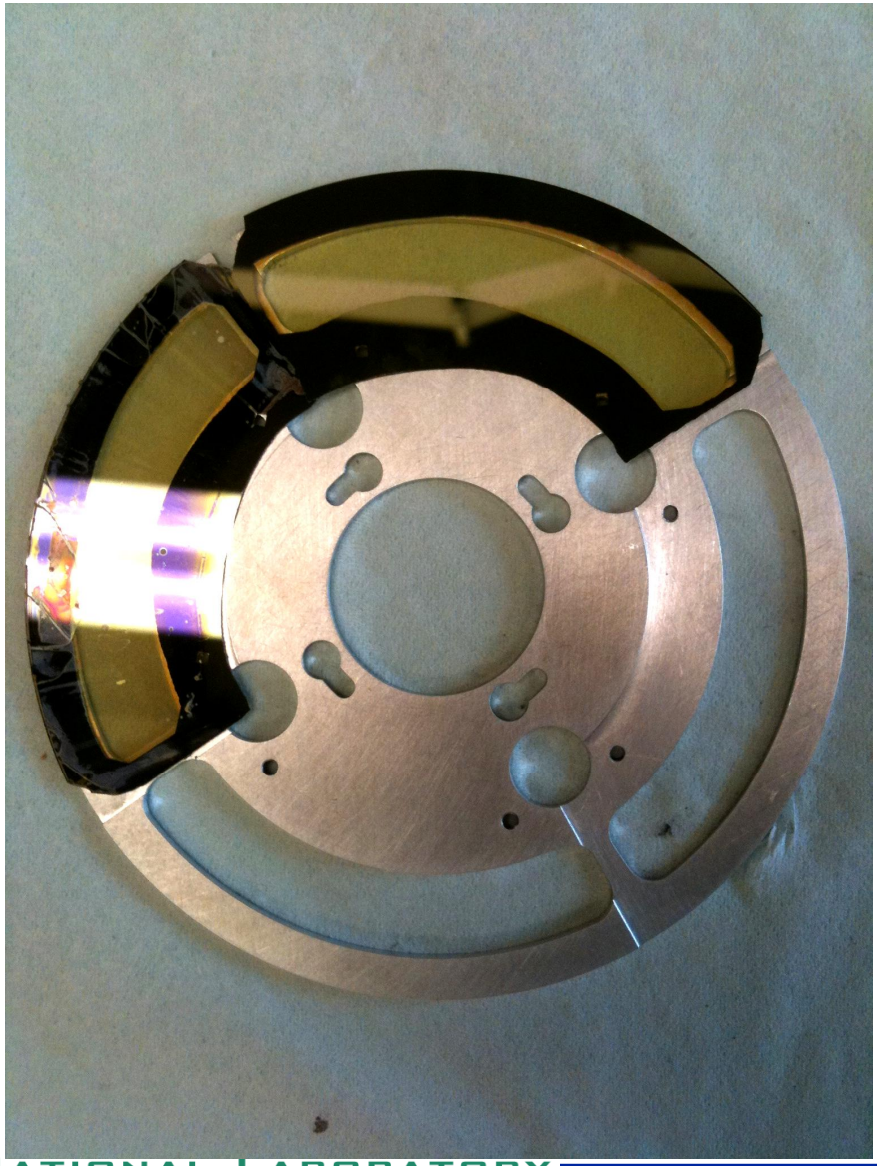
M. Garcia, M. Ali , N. Chang, T. Parsons-Moss, P.. Ashby, J. Gates, L. Stavsetra, K. Gregorich, H. Nitsche, Nucl. Instr. Meth. A., 2008

Several Generations of Spin Coaters



Newest Spin Coater and Target Wheel



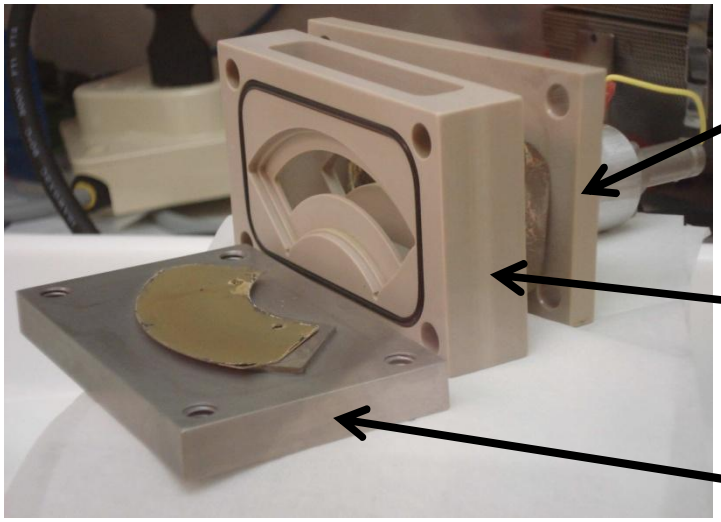


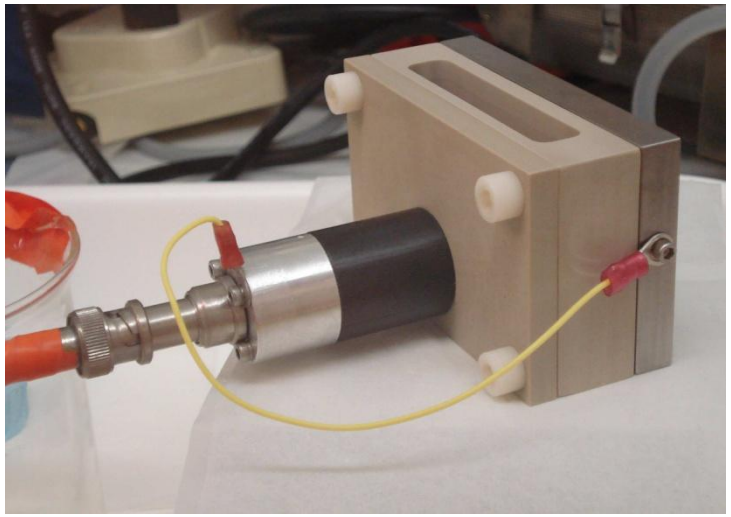
Molecular Deposition: Plating Cell and Procedure

- ^{242}Pu-nitrate in 23-mL isopropanol
- Calcination reaction:

$$Pu(NO_3)_4*5H_2O \rightarrow PuO_2 + 3.4\ NO_2 + 0.6\ NO + 1.3\ O_2 + 5\ H_2O$$

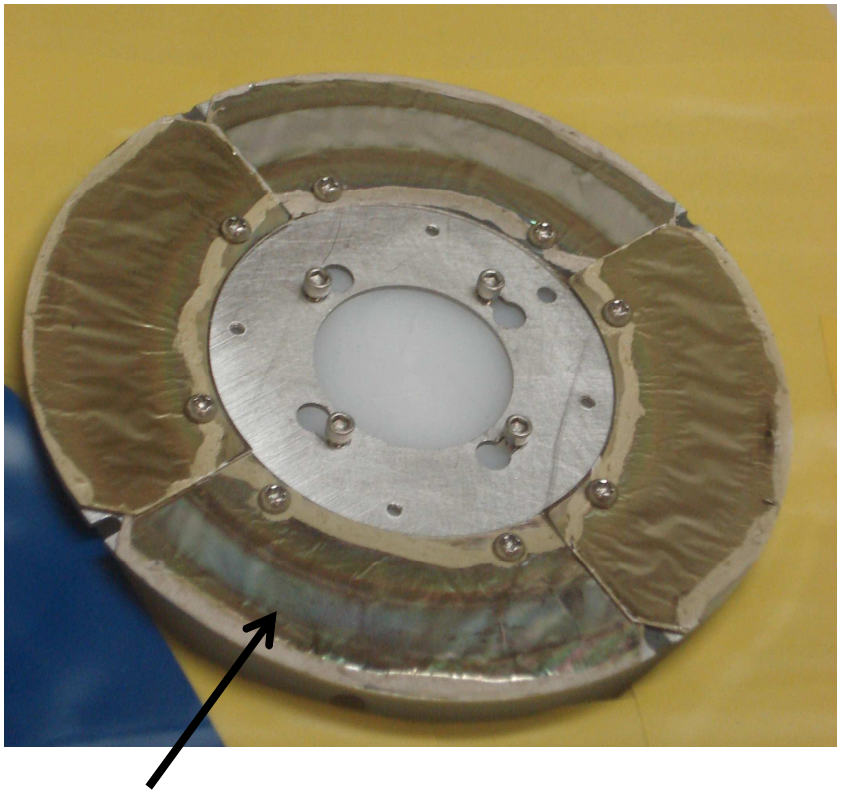
- One layer deposition < 1.0 mA/cm^2, 150-200 V for 3-5 hours

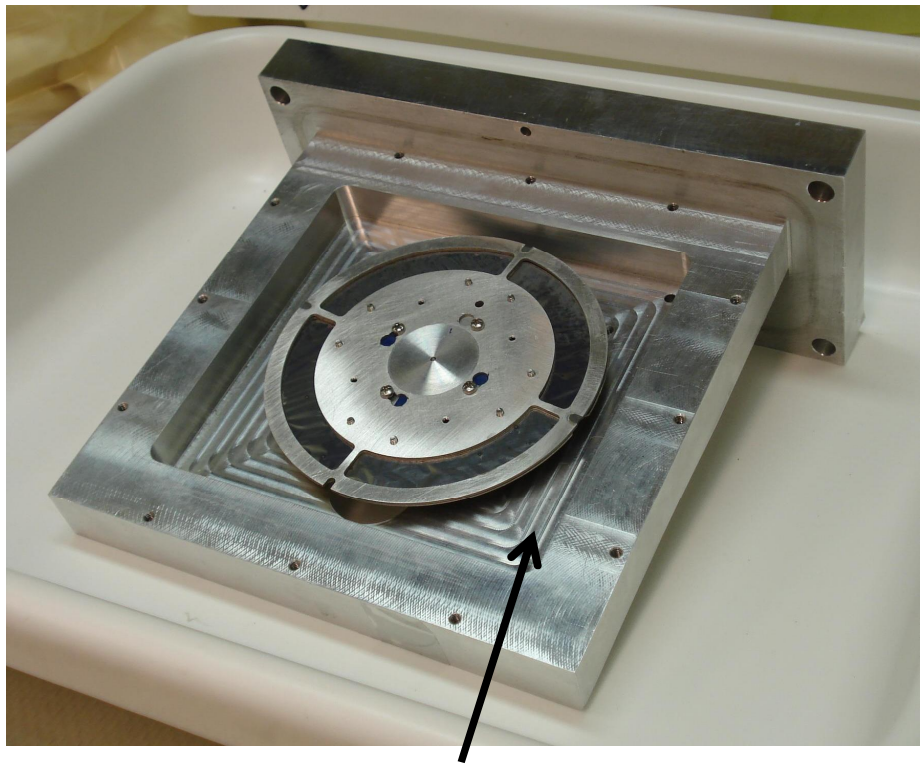




BGS Plutonium Target Assembly
PuO_2 (>99.9% ^{242}Pu)

Upstream side of cassette





440, 340, 320, and 270 μg/cm², 2.4 mm Ti

Cooling water channel inside

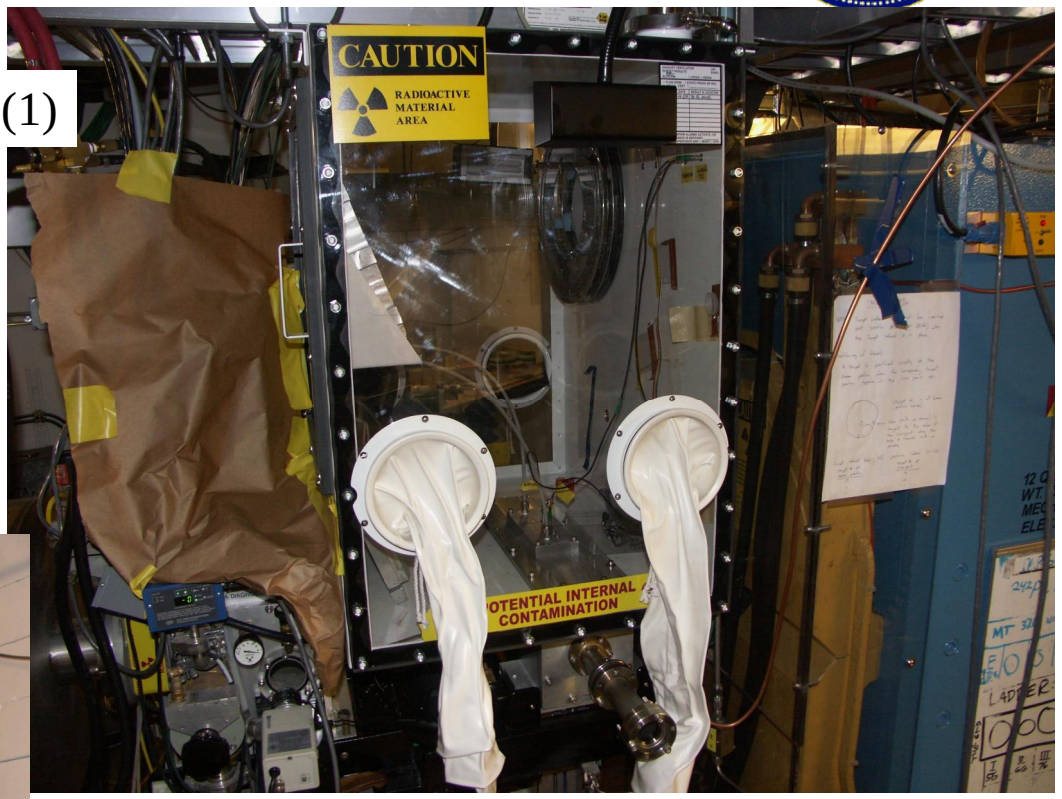
^{242}Pu Experiments at the Berkeley Gas-filled Separator

BGS upgrades:

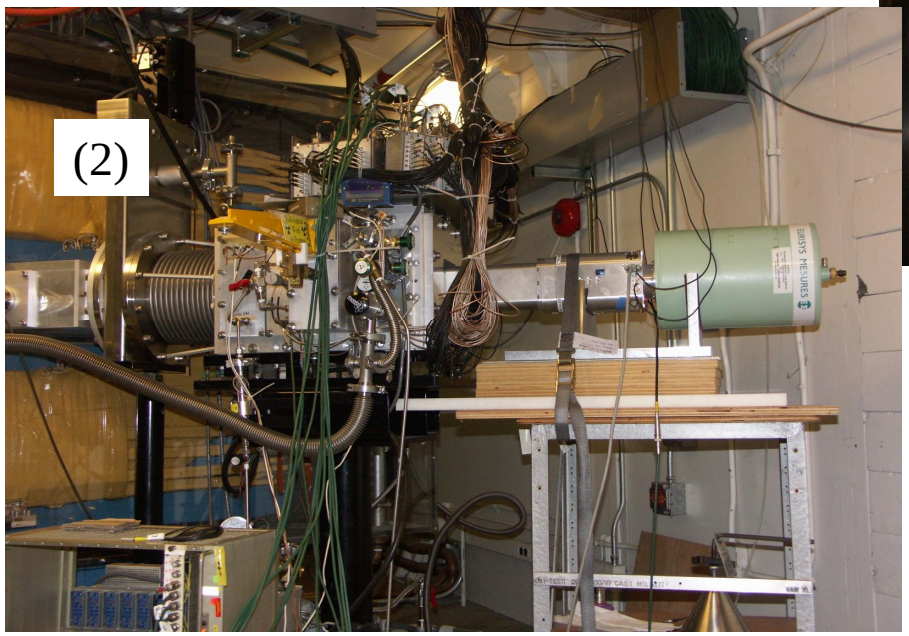
(1) Radioactivity Containment Facility at BGS target

(2) Ge clover *γ*-ray detector behind BGS detectors

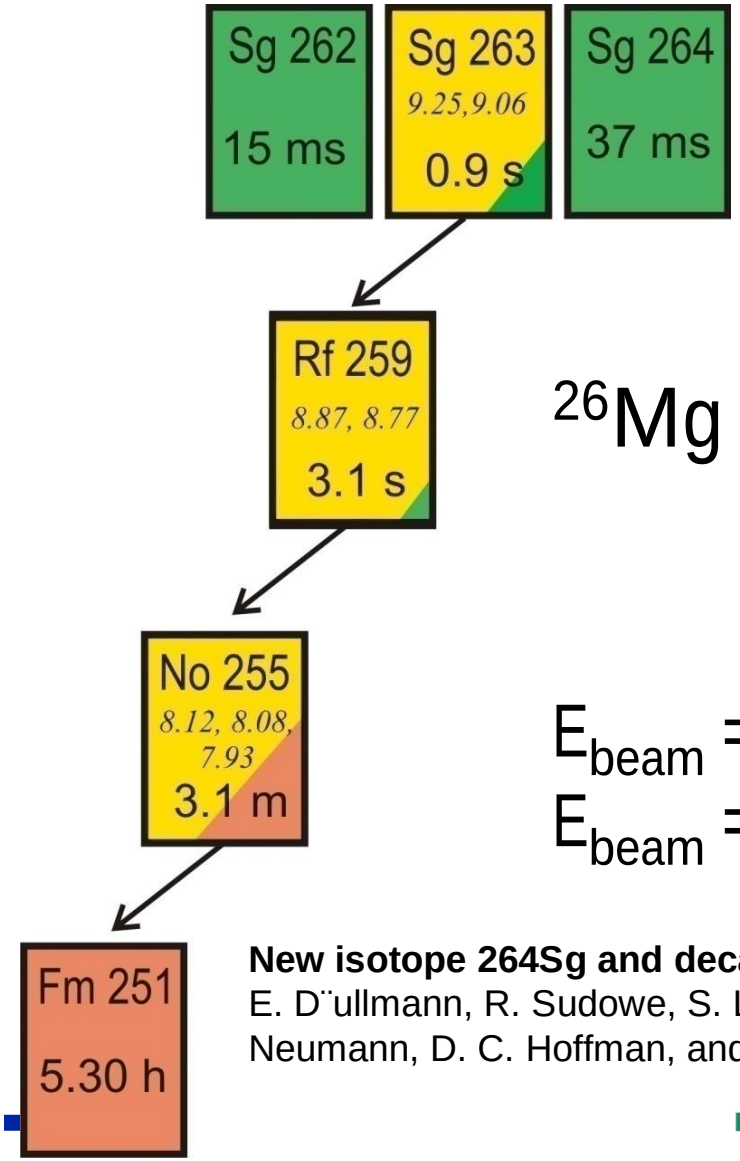
(1)



(2)



Target Test Reaction: $^{26}Mg + ^{242}Pu$



$$^{26}Mg + ^{242}Pu \longrightarrow ^{268}Sg^{*} \begin{cases} ^{263}Sg + 5n \\ ^{262}Sg + 6n \end{cases}$$

$E_{beam} = 157$ MeV ==> $E^{*}_{CN} = 57$ MeV

$E_{beam} = 149.5$ MeV ==> $E^{*}_{CN} = 50$ MeV

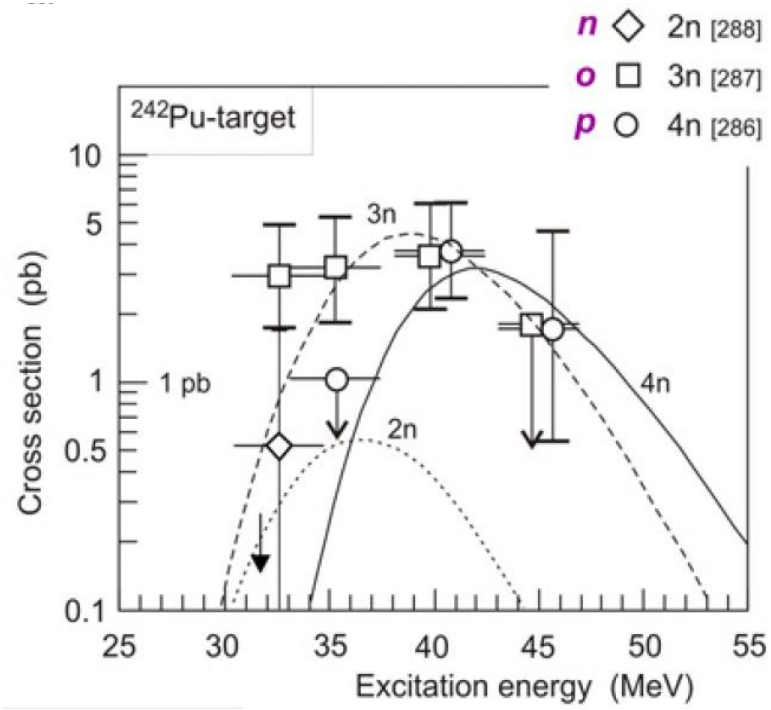
New isotope 264Sg and decay properties of 262–264Sg, K. E. Gregorich, J. M. Gates, Ch. E. D¨ullmann, R. Sudowe, S. L. Nelson, M. A. Garcia, I. Dragojevi´c, C. M. Folden III, S. H. Neumann, D. C. Hoffman, and H., Phys. Rev. C 74, 044611, 2006

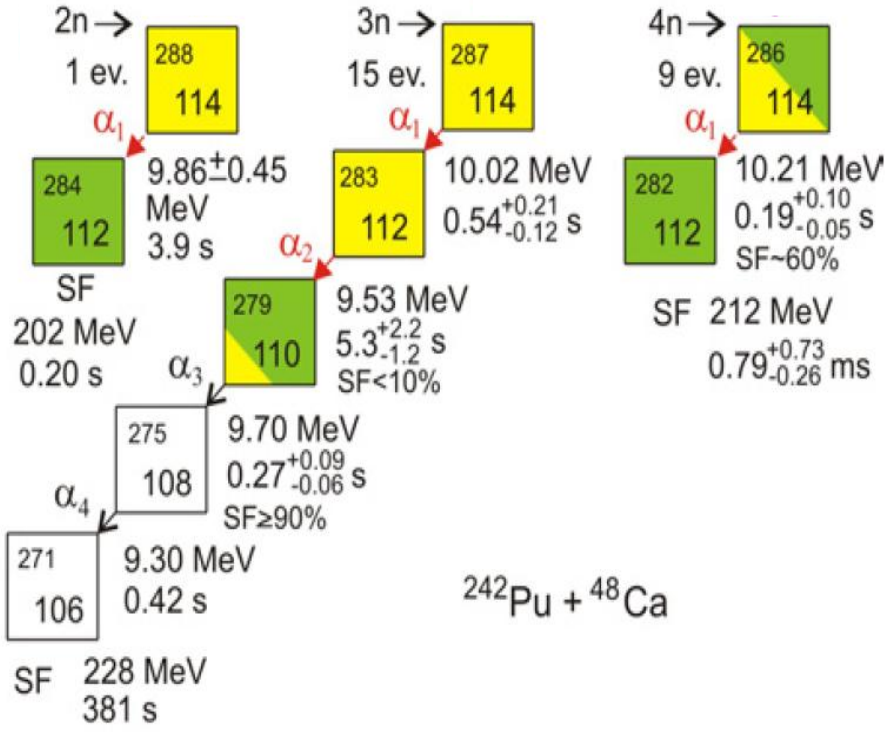
Results: $^{26}Mg + ^{242}Pu$

E_{beam}/E^*_{CN}(MeV)	^{262}Sg	σ(6n) (pb)	^{263}Sg	σ(5n) (pb)	$^{262}Sg + ^{264}Sg$	σ(4n+6n) (pb)
157 / 57	6	79^{+47}_{-31}	1	34^{+77}_{-28}		
149.5 / 50			4	135^{+106}_{-71}	6	79^{+47}_{-31}

-increased fusion cross sections for compound nucleus formation with higher Z targets

Dubna Results of $^{242}Pu(^{48}Ca,2\text{-}4n)^{288\text{-}286}114$





Oganessian *et al.*, J. Phys. G **34**, R165 (2007)

- **24 decay chains in 2- 4 *n* channels**
- **σ_{3n}= 3.6 pb, σ_{4n}= 4.5 pb at E_{LAB}= 244 MeV / E*= 41 MeV**

$^{48}Ca + ^{242}Pu \rightarrow ^{286,287}114$

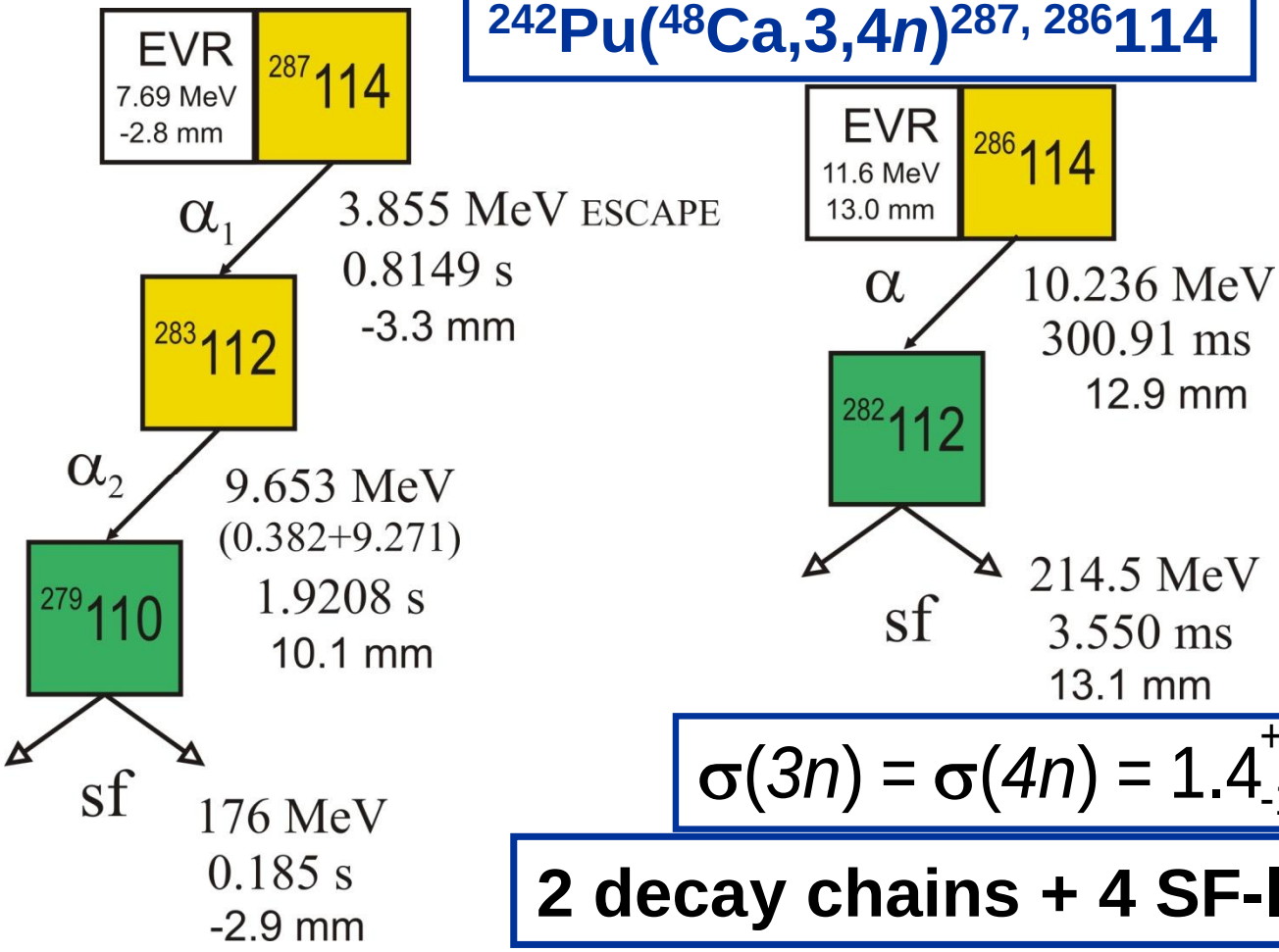
- January 21-30, 2009, at Berkeley Lab
- Eight days of $^{48}Ca^{11+}$ beam from AECR source
- Average beam intensity: I = 300-400 pnA
- Energy in the center of the target :

  E_{LAB} = 244 MeV, E^* = 41 MeV

- Beam intensity and target integrity controlled on-line by Rutherford detectors
- Two decay chains observed + 4 SF-like events

Independent Verification of Element 114 Production

$^{242}Pu(^{48}Ca,3,4n)^{287,\ 286}114$



$\sigma(3n) = \sigma(4n) = 1.4^{+3.2}_{-1.2}$ pb

2 decay chains + 4 SF-like events

L. Stavsetra, K. E. Gregorich, J. Dvorak, P.A. Ellison, I. Dragojević, M.A. Garcia, H. Nitsche, Independent verification of element 114 production in the ^{48}Ca + ^{242}Pu reaction. Phys. Rev. Lett., 103, 132502, 2009,.

Random Rates

TABLE III. Expected numbers of random correlations for sequences: EVR-like event followed by SF, α-SF, and α-α-SF, for the two parts of the experiment, referred to by the magnetic settings of the separator. The evaluated random rates are calculated for a ± 1.5-mm vertical position window and a time window of 20 seconds.

	2.18 Tm setting	2.24 Tm setting
EVR-SF	0.022	6.3×10^{-4}
EVR-α-SF	4.3×10^{-7}	3.7×10^{-8}
EVR-α-α-SF	1.0×10^{-10}	2.8×10^{-12}

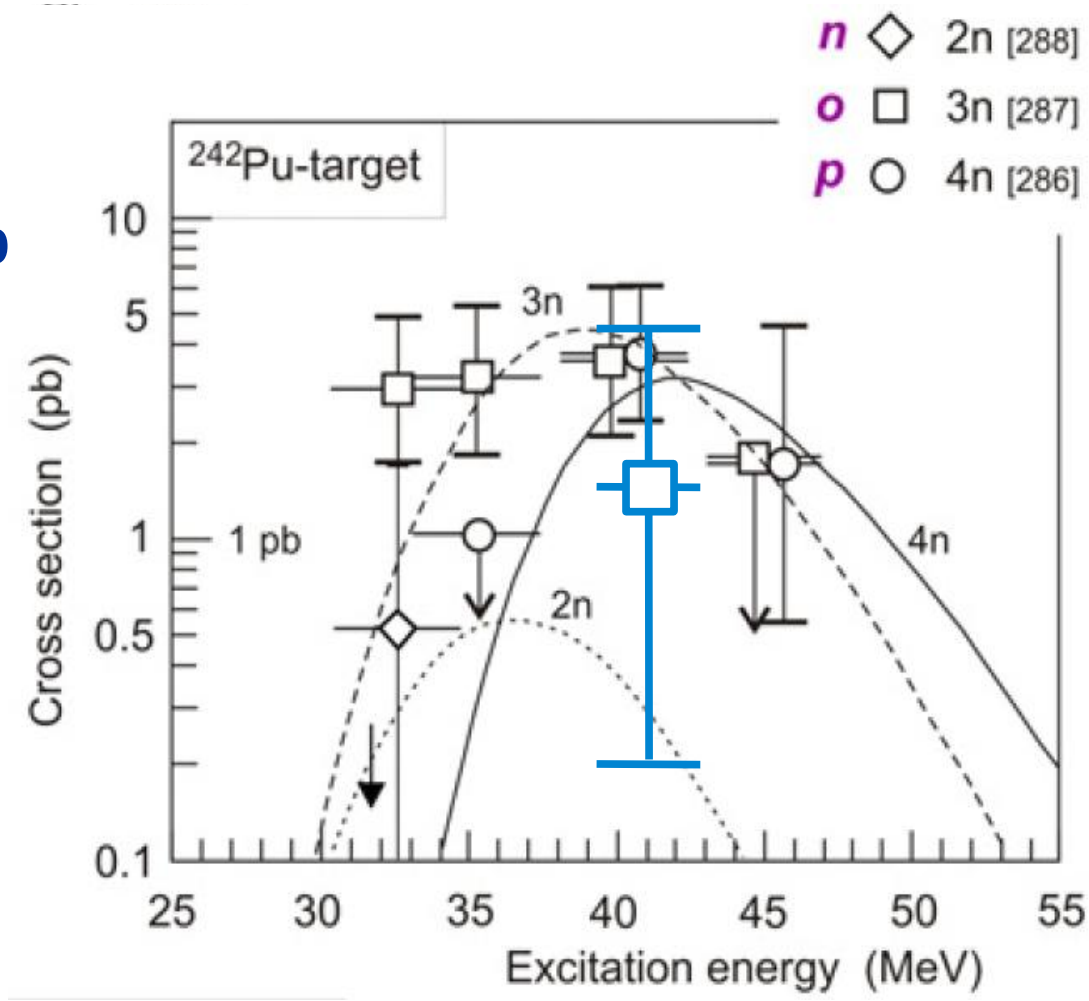
Stavsetra *et al.*, Phys. Rev. Letters, **103**, 132502 (2009)

Cross Sections

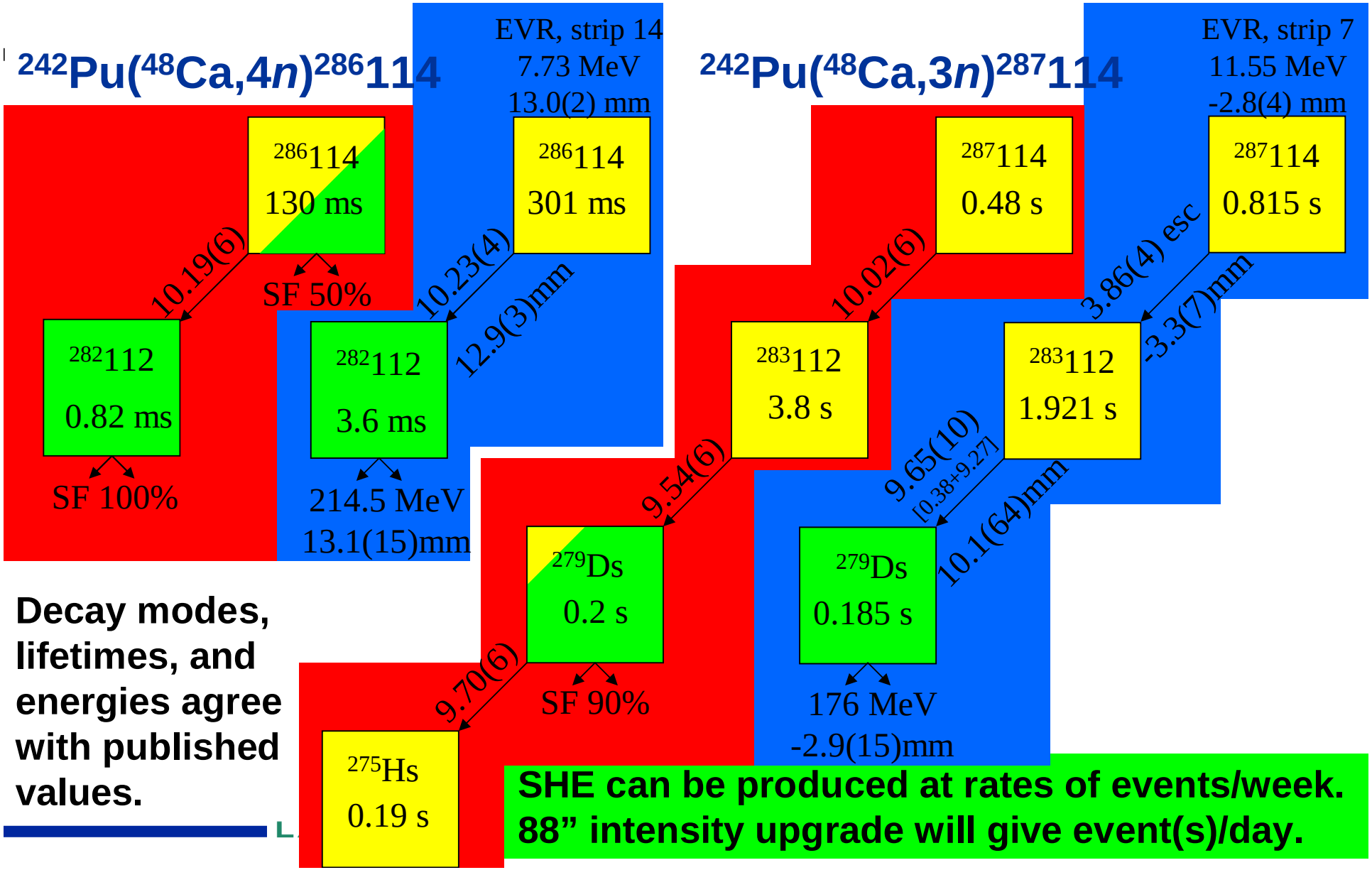
Six chains expected, obtained two (9% probability)

$\sigma_{3n} = \sigma_{4n} = 1.4^{+3.2}_{-1.2}$ pb

Both events at high Bρ edge of the detector
→ lower efficiency if the real Bρ > 2.3 Tm

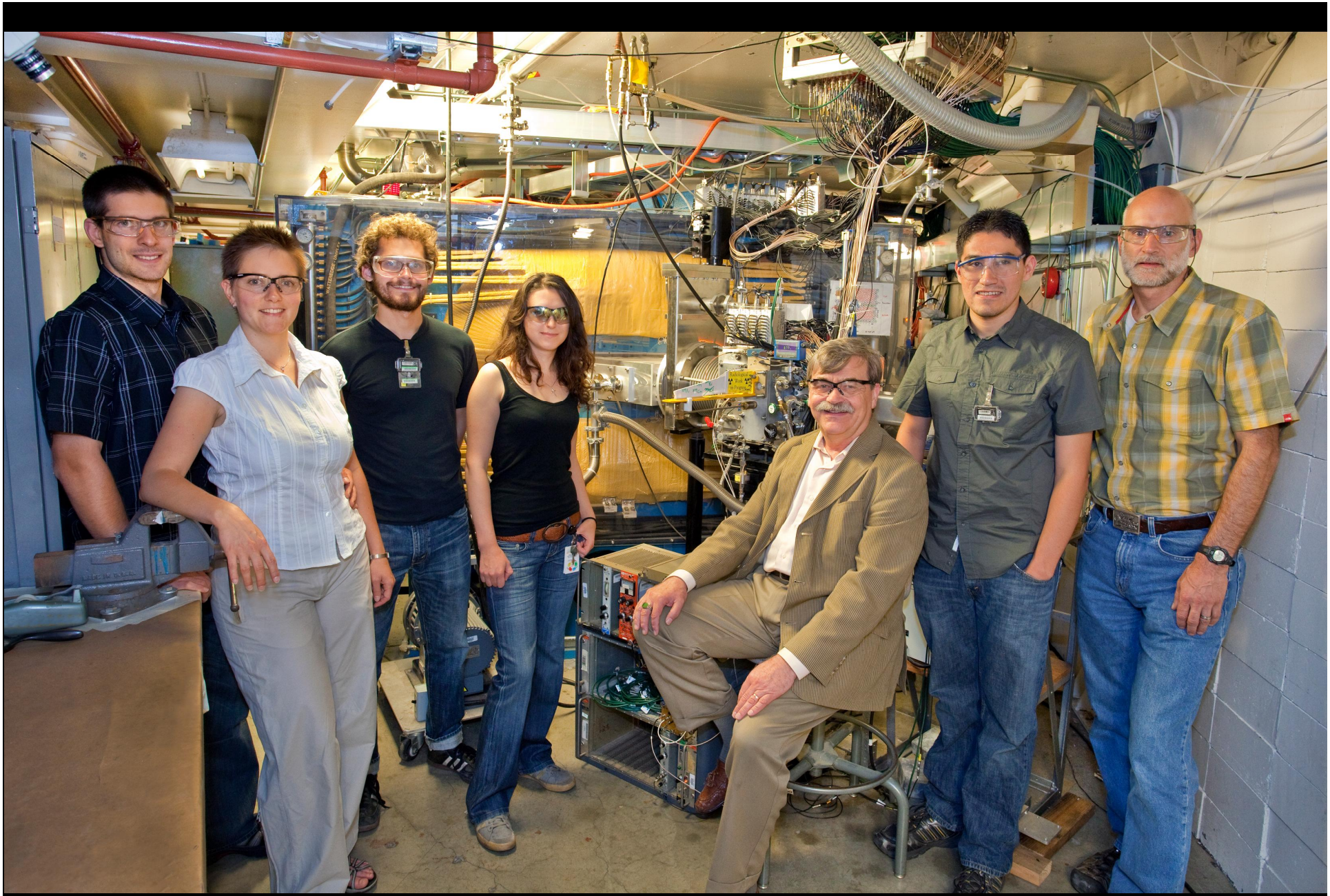


Reported Decay Properties for $^{286}114$ and $^{287}114$ Observed in BGS $^{242}Pu(^{48}Ca,xn)^{290-x}114$ Experiment



Decay modes, lifetimes, and energies agree with published values.

SHE can be produced at rates of events/week. 88" intensity upgrade will give event(s)/day.



+ Liv Stavsetra

Determination of Z and A of Single Atoms

RF gas catcher and mass analyzer after the BGS

Produce SHE in reaction such as $^{244}Pu(^{48}Ca,3n)^{289}114$

Isolate with Berkeley Gas-filled Separator

$^{289}114$ passes through MYLAR window and stops in high-purity He (retains 1+ charge)

Focusing RF field directs 1+ ion toward exit orifice, where it is carried by gas flow

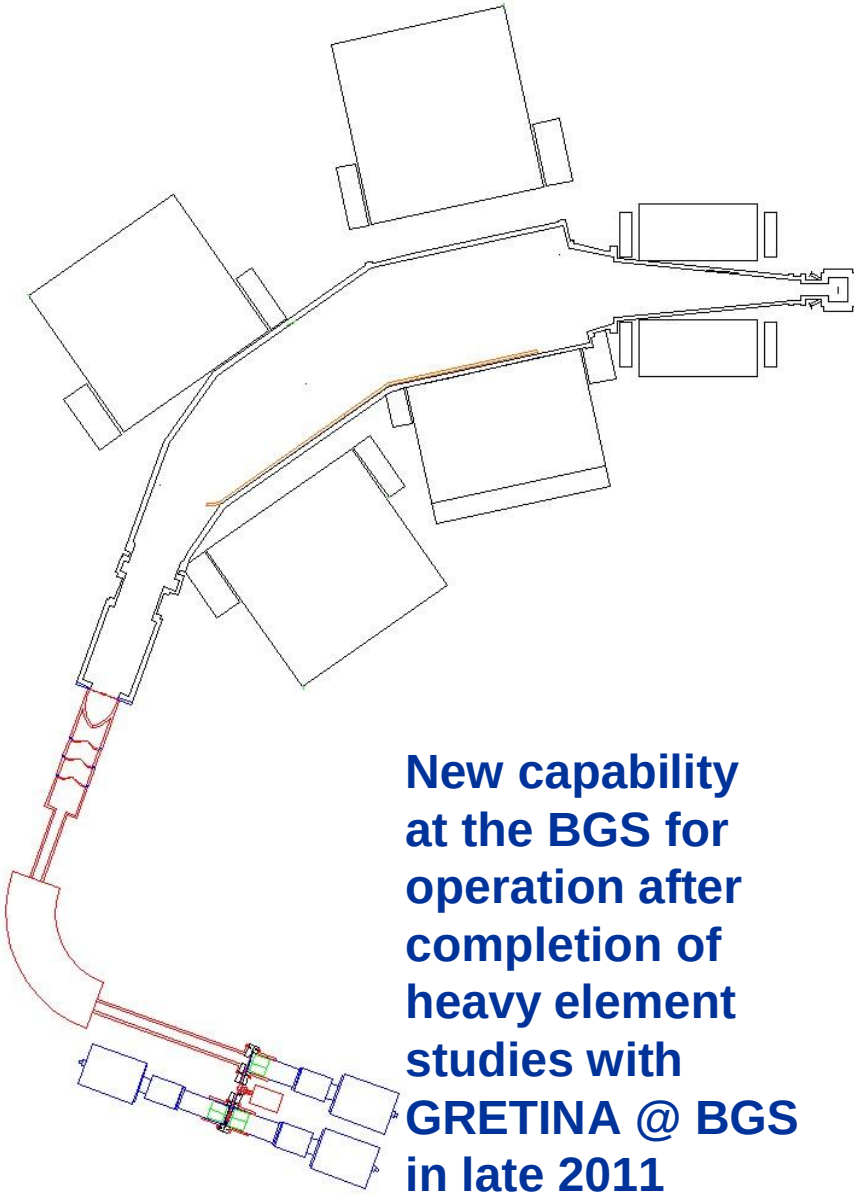
Gas skimming, differential pumping, and acceleration to ground potential results in "beam" of 1+ ions

1+ ion is sent through mass analysis magnet for determination of *A*

1+ ion is stopped on rotating wheel system for measurement of *α*-*γ* coincidences

α-decay of odd-*N* SHE populates analog state in daughter. Internal conversion of analog state γ-decay produces k X-ray

k X-ray of daughter is detected in coincidence with *γ*-decay, providing Z identification



New capability at the BGS for operation after completion of heavy element studies with GRETINA @ BGS in late 2011

Summary

- Targets produced by the PAD method are superior to traditional targets in regards to homogeneity, physical and beam stability
- LBNL ready for highest intensity beams from AECR at 88-inch cyclotron
- First direct verification of ^{242}Pu(^{48}Ca,3,4*n*)$^{287,\ 286}$114
  — two decay chains observed + 4 SF-like events
- A new A and Z measuring facility is being planned at the BGS

Thank You for Your Attention