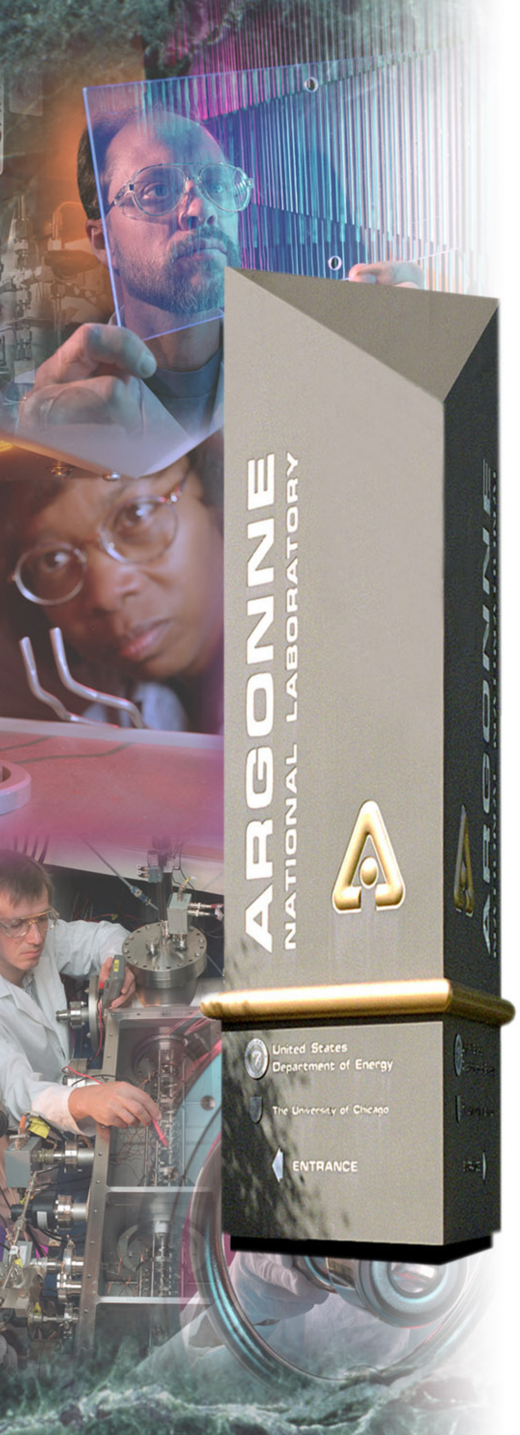



# Target Developments for the U.S. Rare Isotope Accelerator

*Conference on High Power Targetry*
*For Future Accelerators*

*Jerry Nolen*
*Physics Division*
*September 11, 2003*

**Argonne National Laboratory**

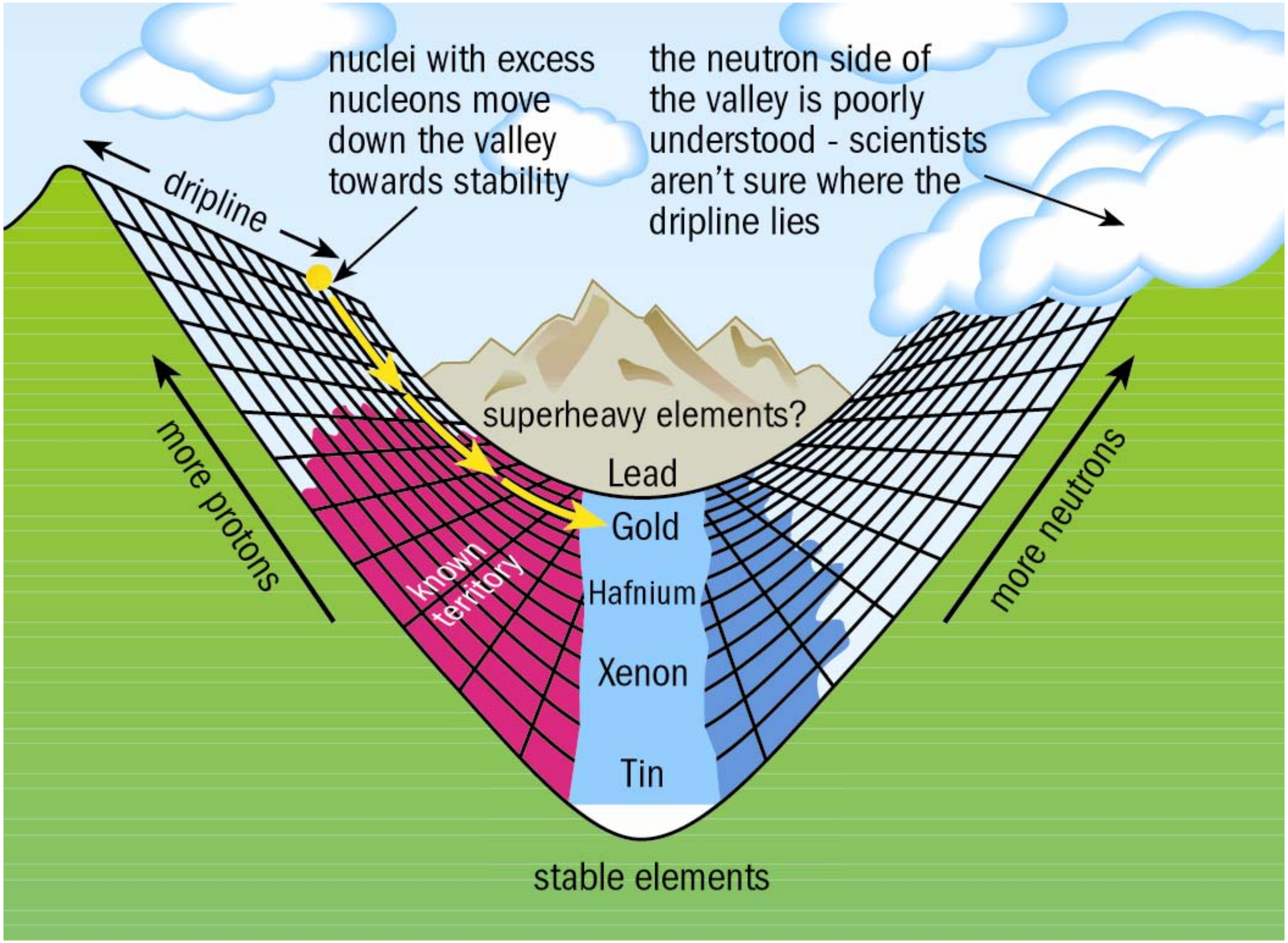
Office of Science
U.S. Department of Energy

*A U.S. Department of Energy*
*Office of Science Laboratory*
*Operated by The University of Chicago*

# *What is RIA?*

- **RIA is a next-generation facility for basic research in nuclear physics**
- **RIA will be a dream-world for addressing open questions in low-energy nuclear physics**
- **RIA will deliver radioactive beams of unprecedented intensity and variety using both ISOL & In-flight methods**

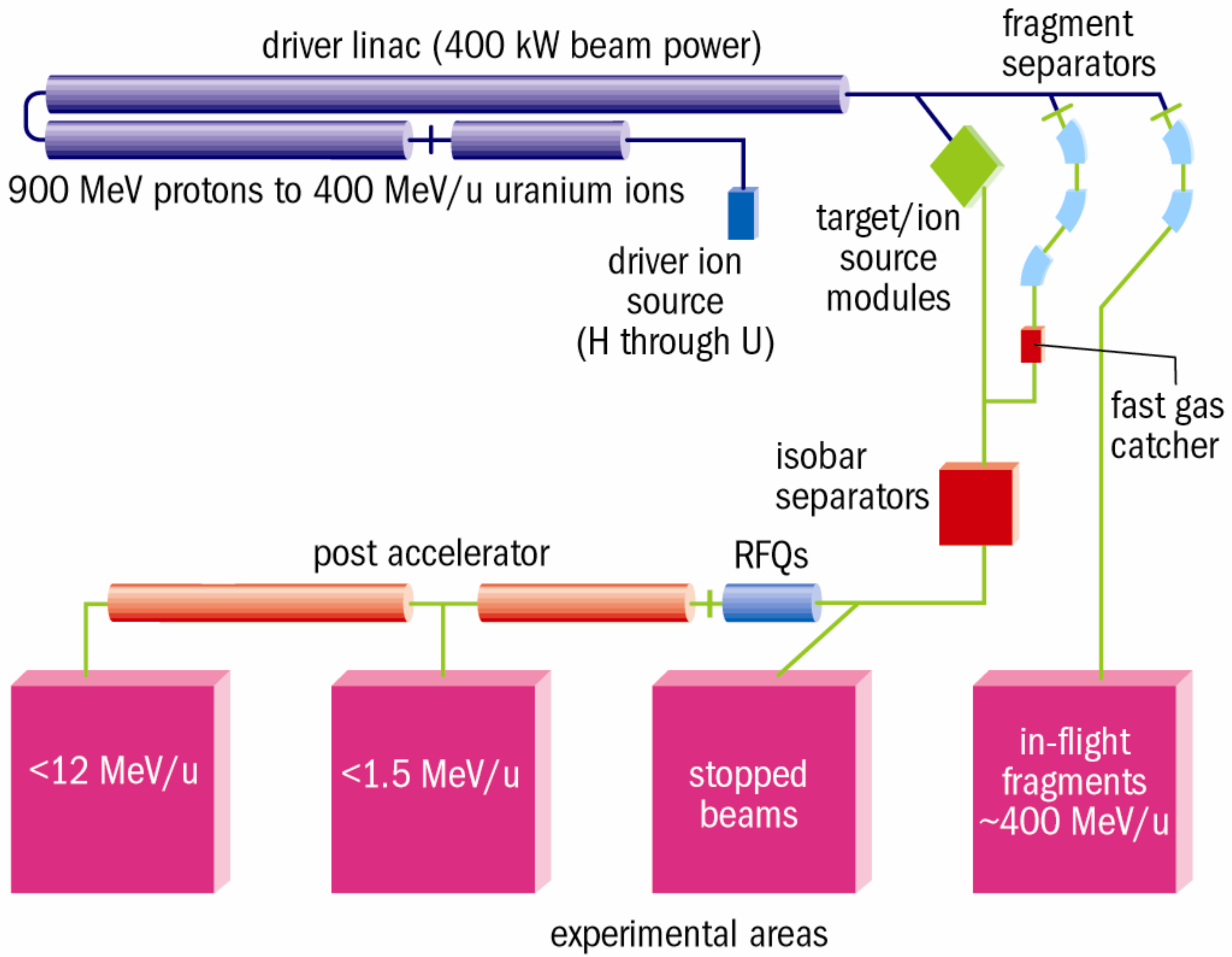
# Rare Isotopes Surround the Valley of Stability



# *The Scientific Case for Rare Isotope Beams*

- **The Origin of the Elements**
- **The Limits of Nuclear Stability**
- **Properties of Nuclei with Extreme Neutron to Proton Ratios**
- **Properties of Bulk Neutron Matter and the Nature of Neutron Stars**
- **Quantum Mechanics of Mesoscopic Systems**
- **Tests of Fundamental Interactions**

# Schematic of the RIA Facility



# *NSAC 2002 Long Range Plan*

**Recommendation: The Rare Isotope Accelerator (RIA) is our highest priority for major new construction.**

**R&D: Eight labs in the U.S. are participating in R&D for the RIA project. MSU & ANL are working together to develop a cost-effective technical plan. Both institutions would like to be the site of RIA.**

## Optimistic time line for RIA

**DOE Critical Decision 0 in 2004, followed by 3 years of design and 4 years of construction. Commission in 2011.**

# *Cost (in FY01$) Reviewed by NSAC*

**Estimated cost of RIA at ANL , including all direct and indirect costs, contingency, and assuming use the existing ATLAS facility and buildings:**

| | |
|---|---|
| **- Total Estimated Cost** | **$695M** |

**Other project costs:**

| | |
|---|---|
| **- R&D** | **$40M** |
| **- CDR & Environmental Studies** | **$15M** |
| **- Pre-operations** | **$135M** |

**Yielding a total project cost:**

| | |
|---|---|
| **- Total Project Cost** | **$885M** |

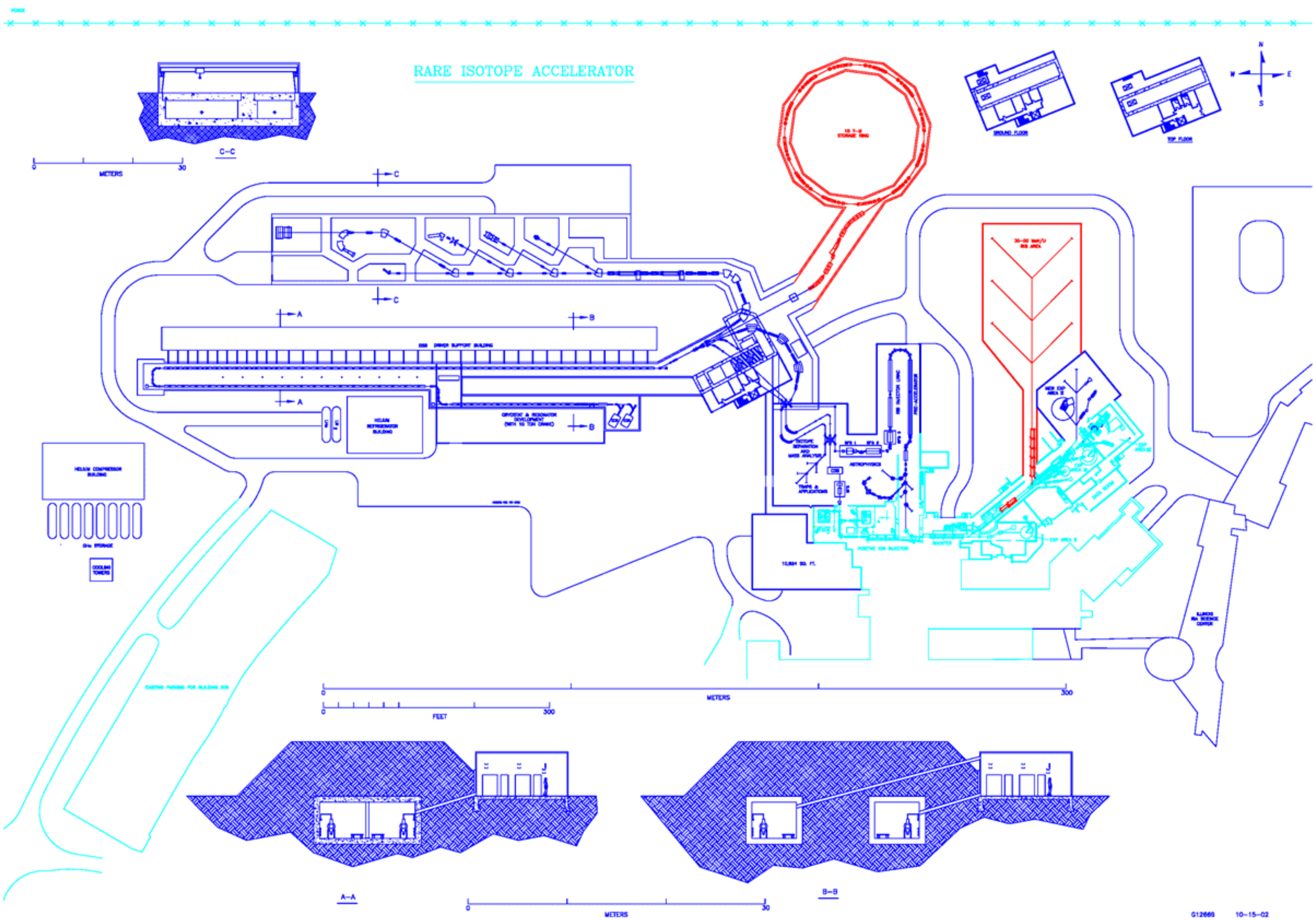
---

| | |
|---|---|
| **Operating budget:** | **~$75M/yr** |

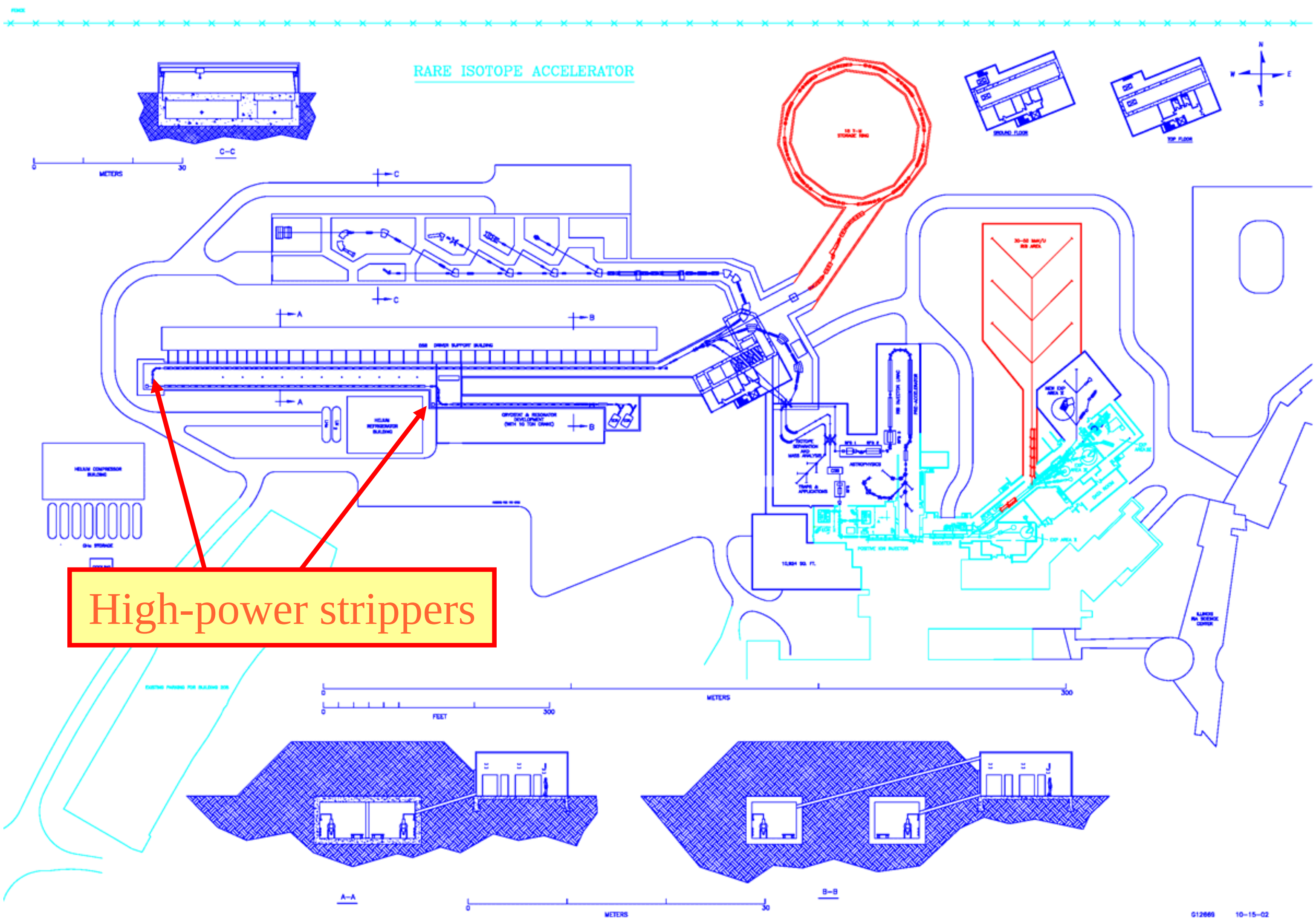
# Important Technical Features of RIA

- High power CW SC Linac Driver (1.4 GV, 400 kW)
    - Advanced ECR Ion Source
    - Accelerate 2 charge states of U from ECR
    - All beams: protons-uranium
    - Superconducting over extended velocity range: 0.2 – 900 MeV/u
    - Multiple-charge-state acceleration after strippers
    - Adapted design to use both SNS cryomodules
    - RF switching to multiple targets
- Large acceptance fragment separators
    1) "Range Bunching" + Fast gas catcher for ISOL
    2) High resolution and high purity for in-flight
- High power density ISOL and fragmentation targets
    - Liquid lithium as target for fragmentation and cooling for n-generator
- Efficient post-acceleration from 1+ ion sources
- Next-generation instrumentation for research with rare isotopes

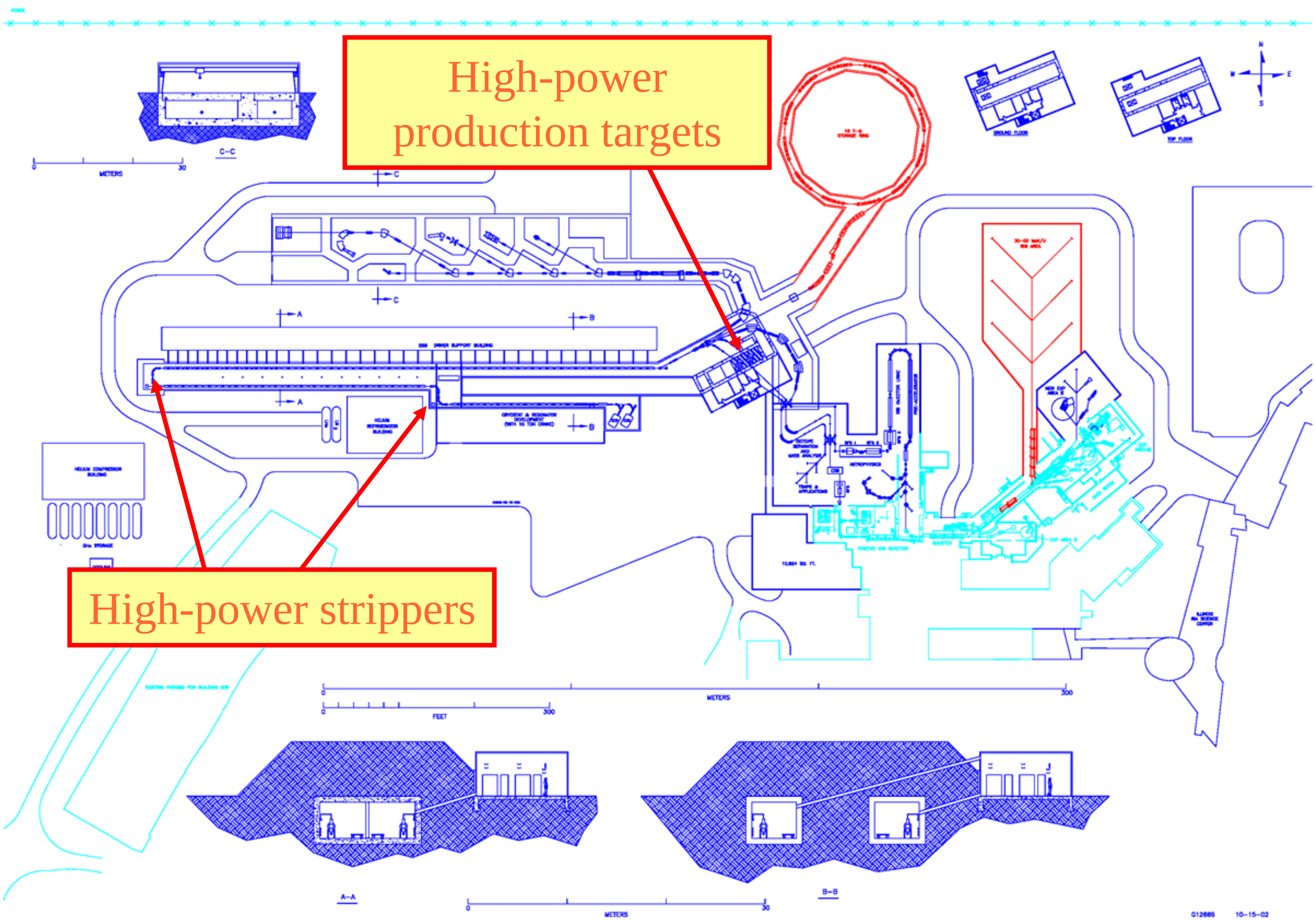
# Detailed RIA Layout



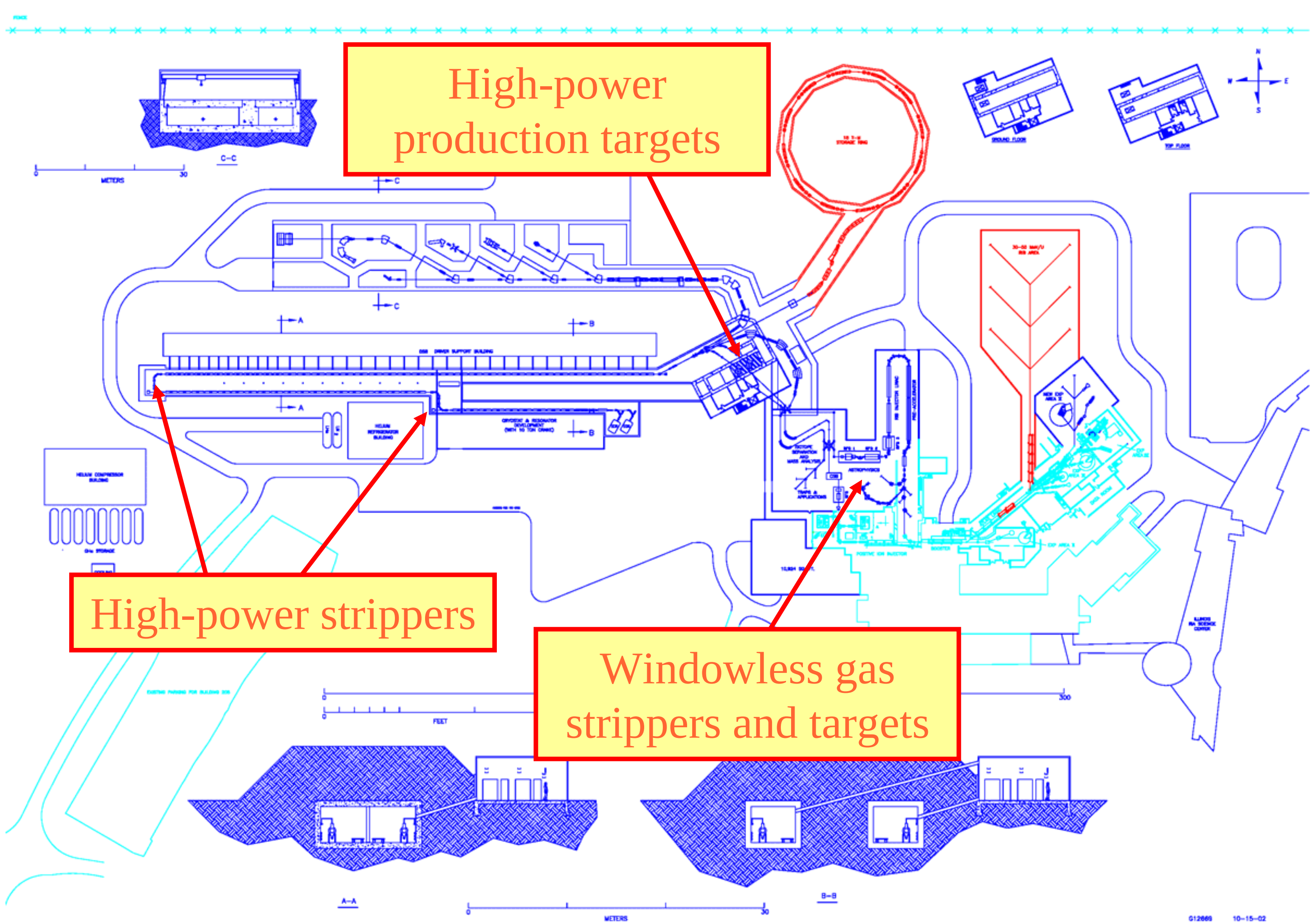
# Detailed RIA Layout



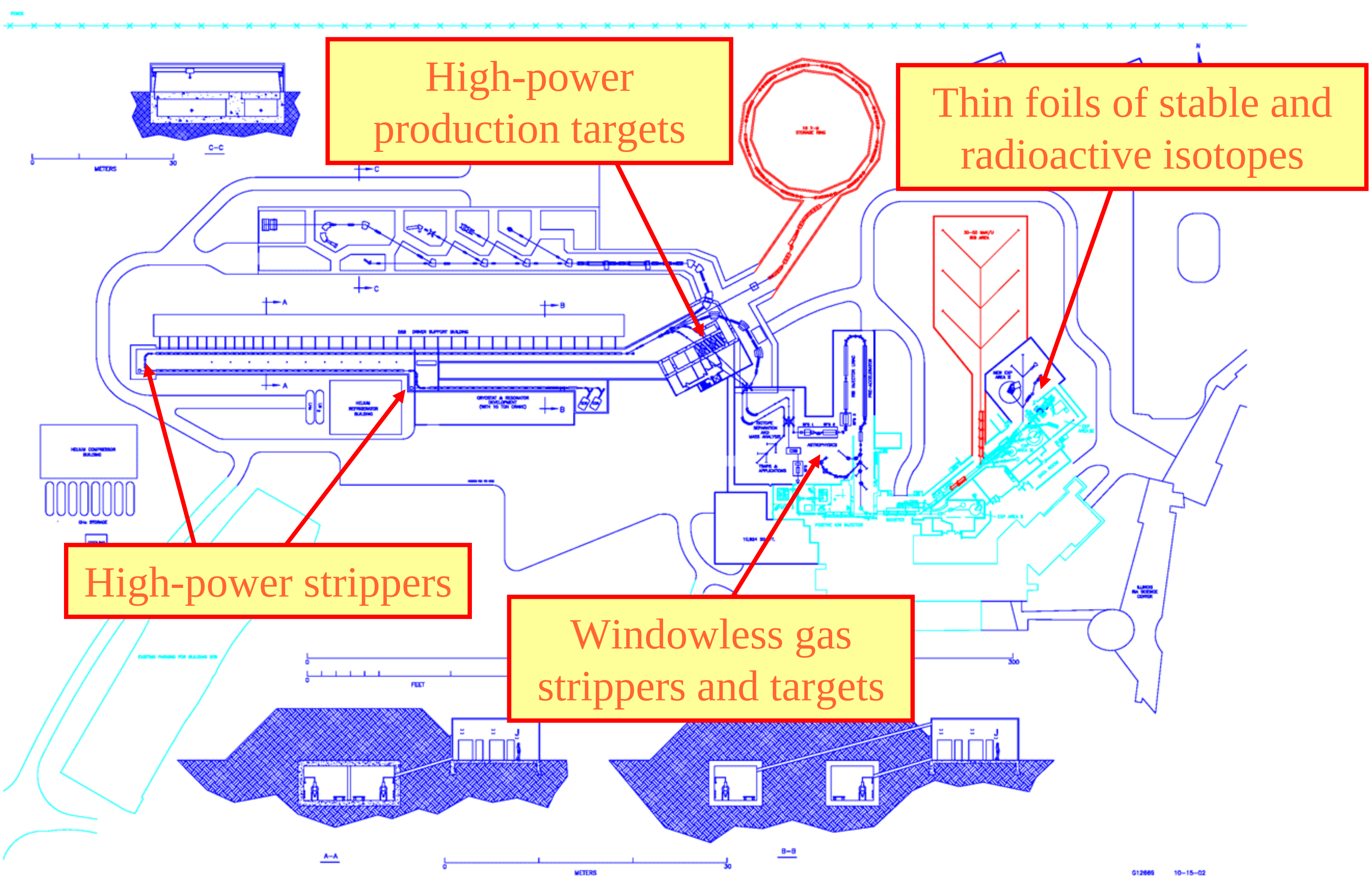
# Detailed RIA Layout



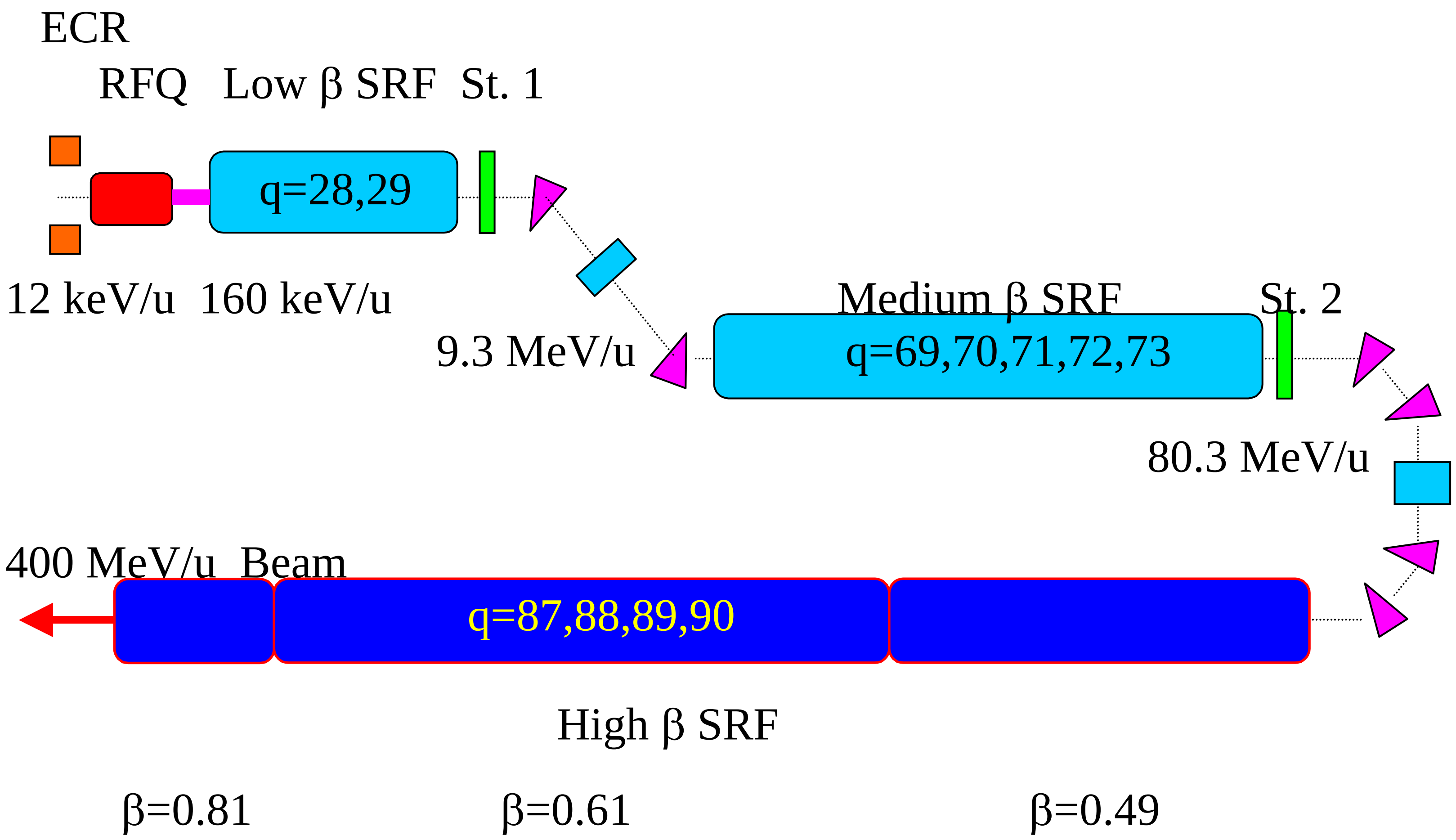
# Detailed RIA Layout



# Detailed RIA Layout



# RIA Driver Linac Structure With Multiple Charge State Capability



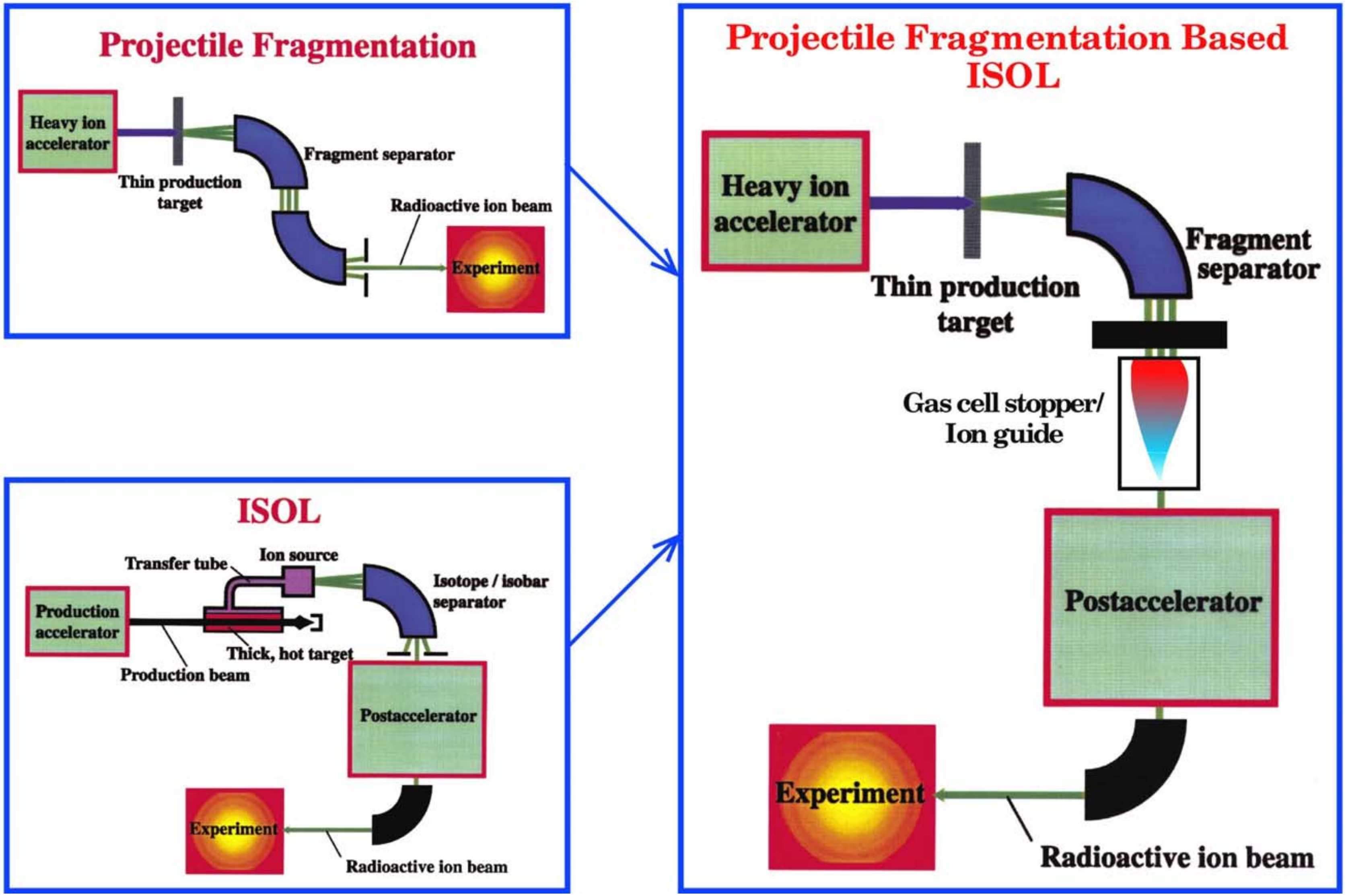
# Partial Beam list for the RIA Driver Linac

| A | I source | Qinj | Qstrip | Qout | I out | Energy out |
|---|---|---|---|---|---|---|
| | pμA | | | | pμA | MeV/u |
| 1 | 556 | 1 | - | 1 | 445 | 899 |
| 3 | 232 | 2 | - | 2 | 186 | 717 |
| 2 | 416 | 1 | - | 1 | 333 | 600 |
| 18 | 54 | 6 | 8 | 8 | 40.3 | 551 |
| 40 | 29 | 8 | 18 | 18 | 18.0 | 554 |
| 86 | 15 | 14 | 33-34 | 36 | 8.8 | 515 |
| 136 | 12 | 18 | 46-48 | 53-54 | 6.2 | 476 |
| 238 | 8 | 28-29 | 69-73 | 87-90 | 4 | 403 |

**400 kW beam power**

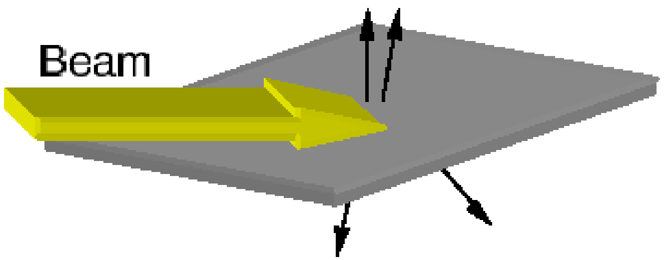
# Projectile Fragmentation Based ISOL Concept with a Multiple Beam (Heavy Ion) Driver

- Fast Extraction Times (~msec)
- Chemical independence
- Isobar separation

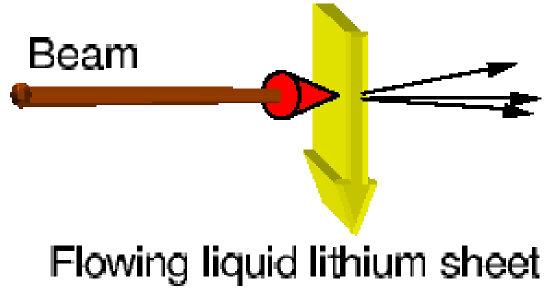


# A Variety of Targets and Production Mechanisms

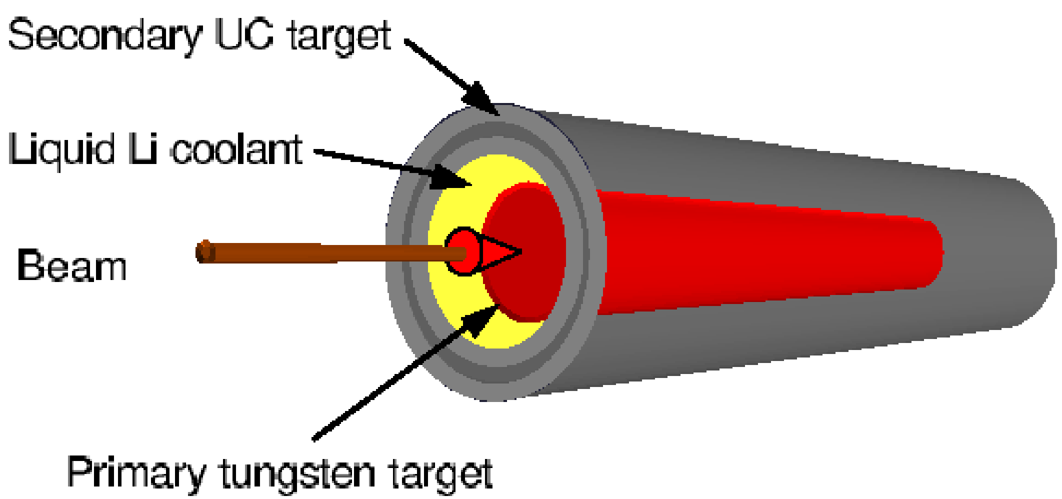
## (a) Tilted spallation target



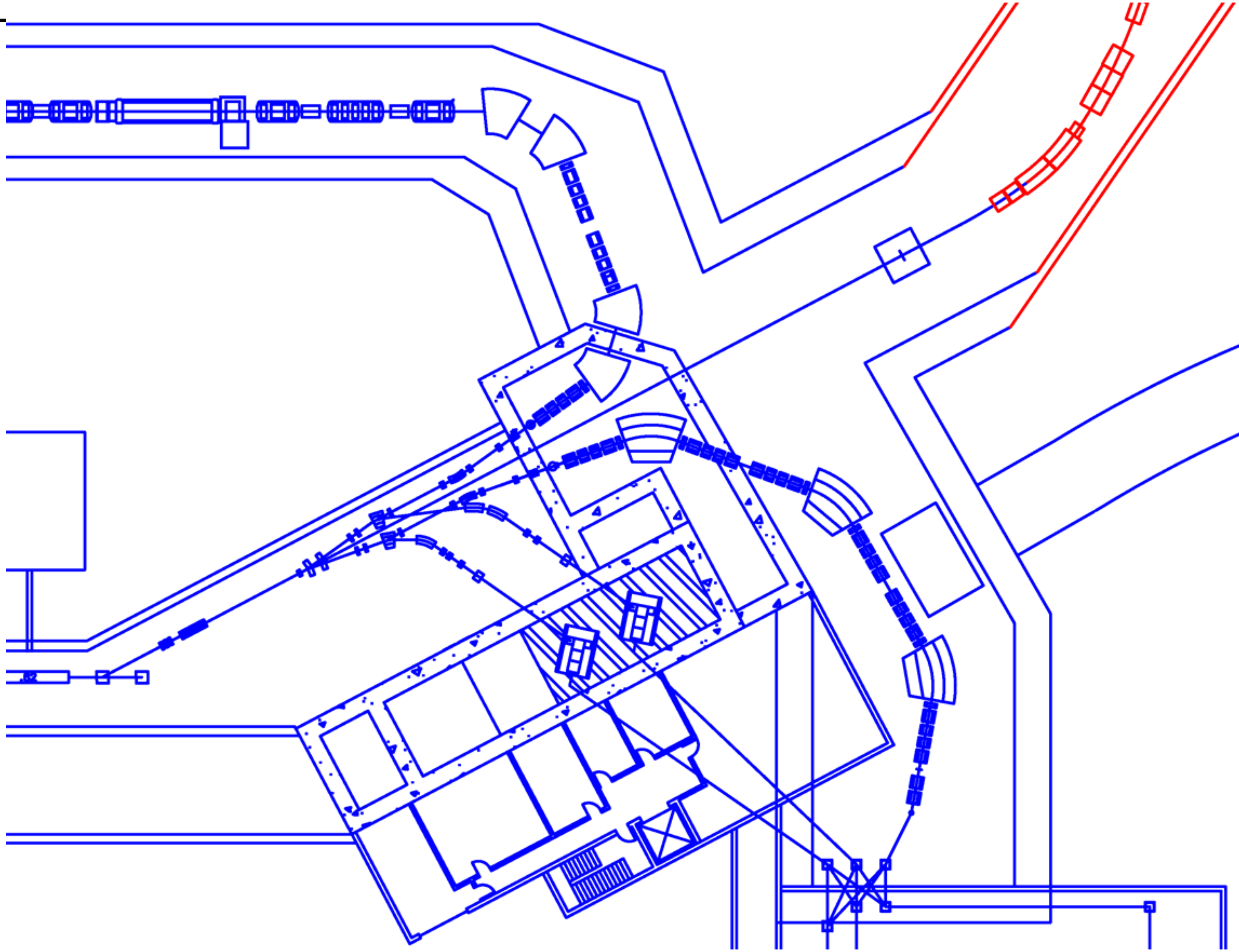

## (b) Liquid lithium target



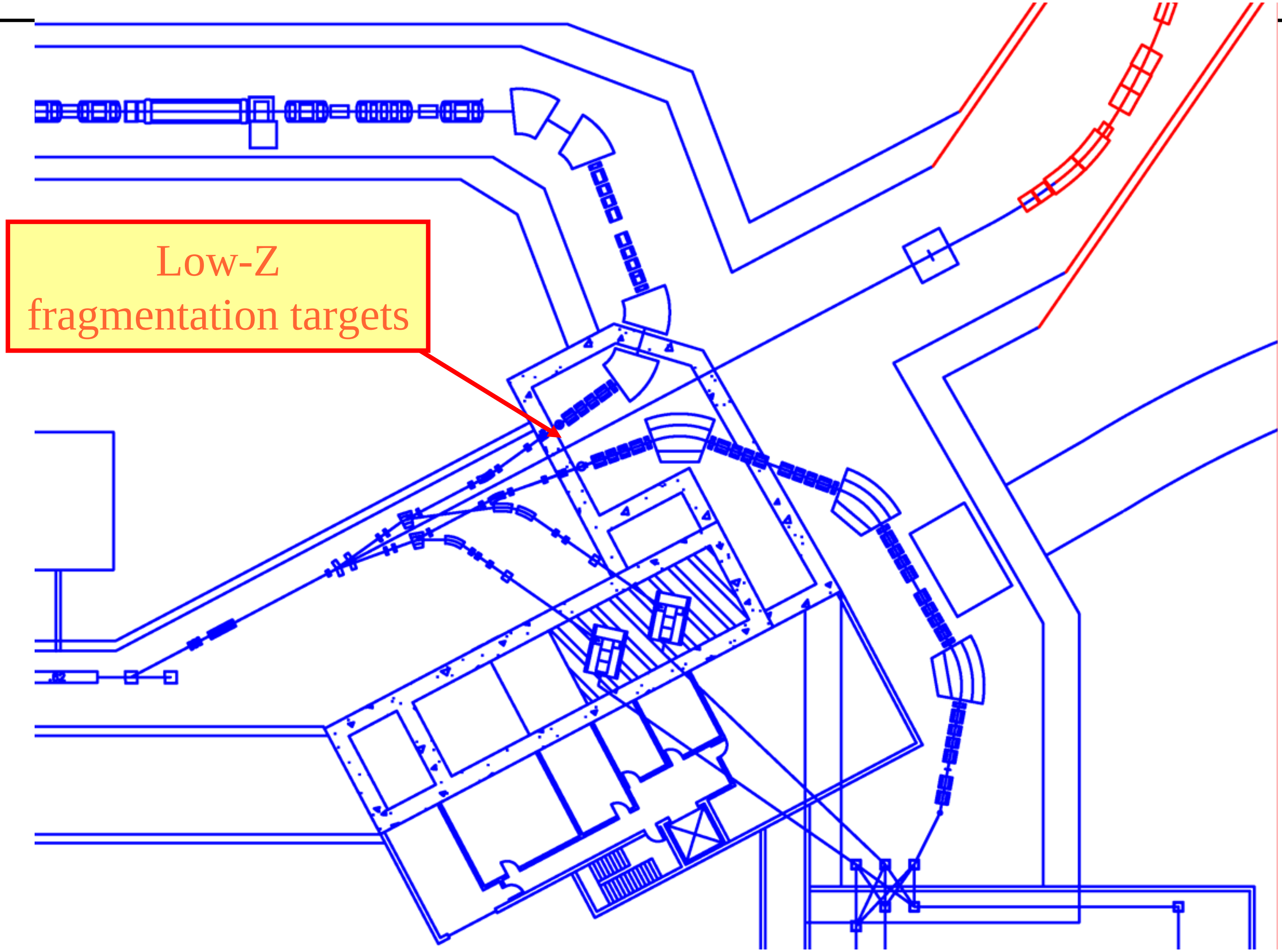

## (c) Two-step neutron-induced fission target



# Production Target Areas and Beam Sharing



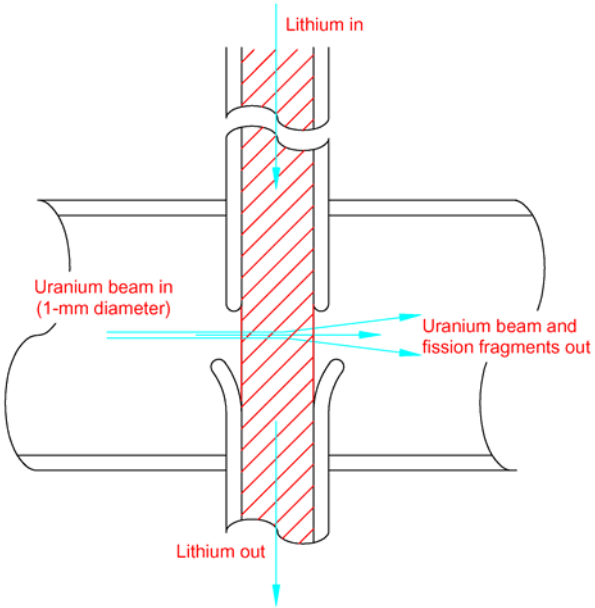
# Production Target Areas and Beam Sharing



# Concept for a windowless liquid lithium target for fragmentation

**Development of windowless liquid lithium targets for fragmentation and fission of 400-kW uranium beams**

J.A. Nolen[1], C.B. Reed[2], A. Hassanein[3], V. J. Novick[2], P. Plotkin[2], and J.R. Specht[1]
[1]*Physics Division*, [2]*Technology Development Division*, [3]*Energy Technology Division*
*Argonne National Laboratory, Argonne, IL 60439, USA*
(Proceedings of EMIS-14, May, 2002, Victoria, B.C., Canada)

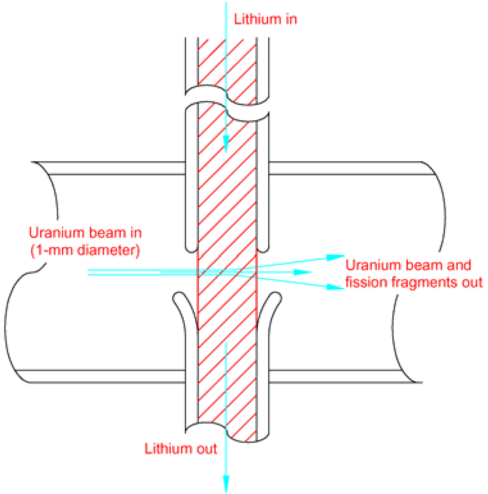


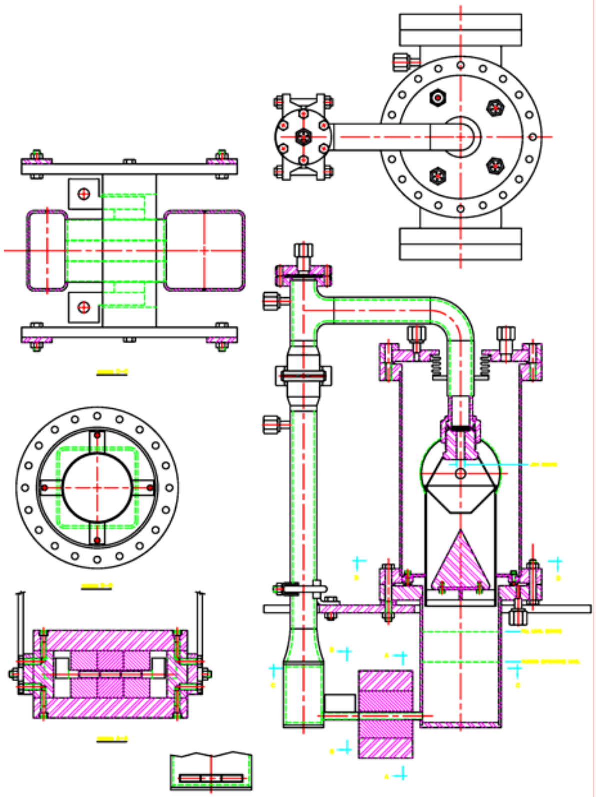

Schematic layout of the concept of a windowless liquid lithium target for in-flight fission or fragmentation of heavy ions up to uranium, designed to work with beam power as high as 400 kW, or 4 $MW/cm^3$.

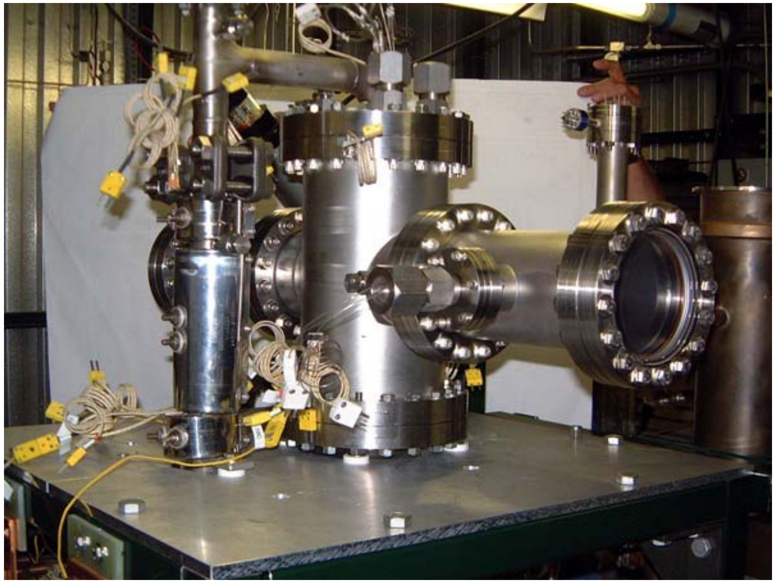
# *The Choice of Liquid Lithium*

- **Low Z (=3)---good from nuclear considerations**
- **Large working temp range $\Delta T \sim 1160$ °C**
  - High boiling point (1342$^{o}$C)
  - Low melting point (181$^{o}$C)
- **Low vapor pressure ($10^{-7}$ Pa at 200$^{o}$C)---only Ga and Sn lower**
- **Lowest pumping power required because:**
  - Lowest density (511 kg/m$^3$)---easiest liquid metal to pump
  - High heat capacity ( $4.4 \times 10^3$ J/kg-K)---highest of liquid metals
  - Low viscosity ($5.4 \times 10^{-4}$ Pa-s)
- **Low Prandtl No. ~0.05 $\Rightarrow$ excellent heat transfer**
- **Applications**
  - Heat Transfer fluid to cool solid targets with light-ion beams
  - Functions as combined coolant and target for high-power heavy-ion beams

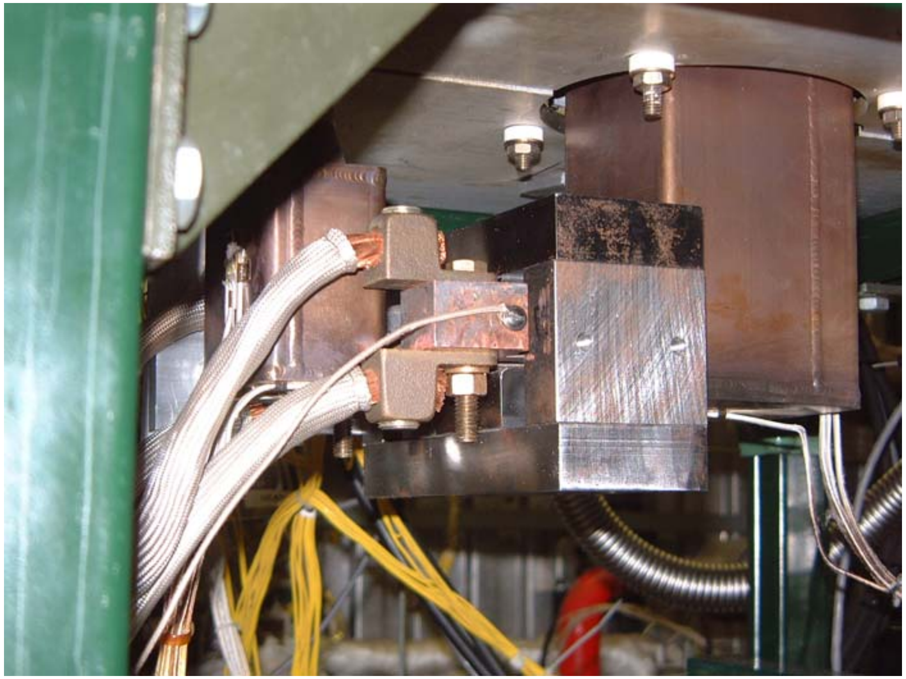
# Windowless Liquid Lithium Target



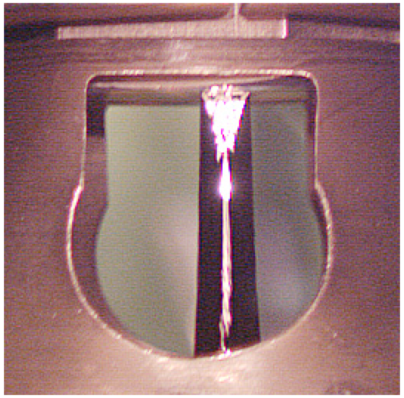


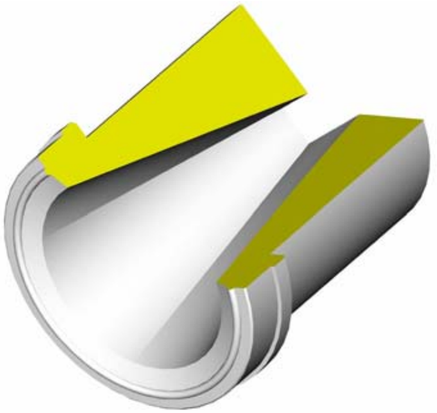
# *Liquid lithium pump, nozzle, and jet*



Permanent magnet, Lorentz-force liquid lithium pump

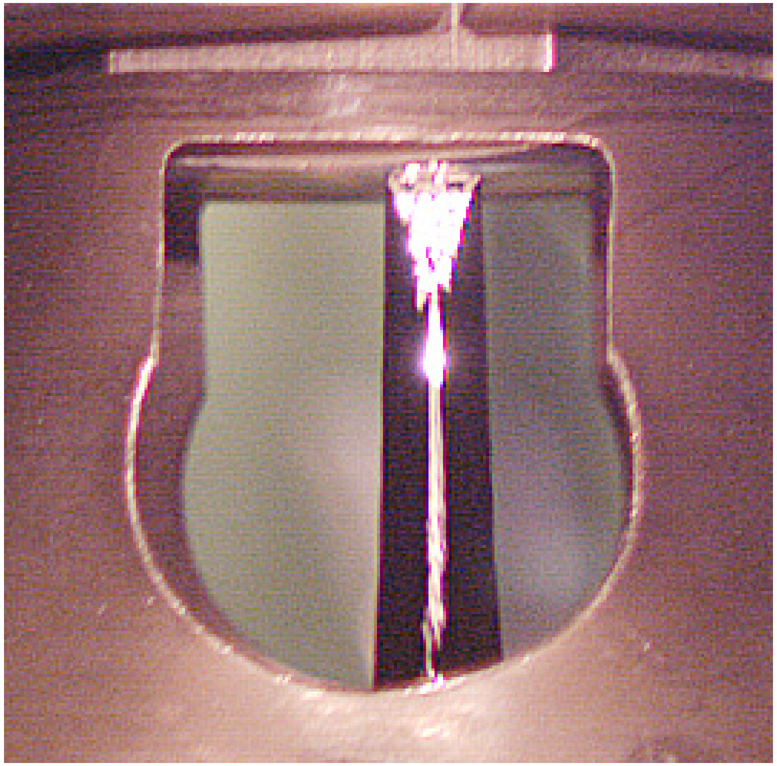
5 mm x 10 mm jet in vacuum





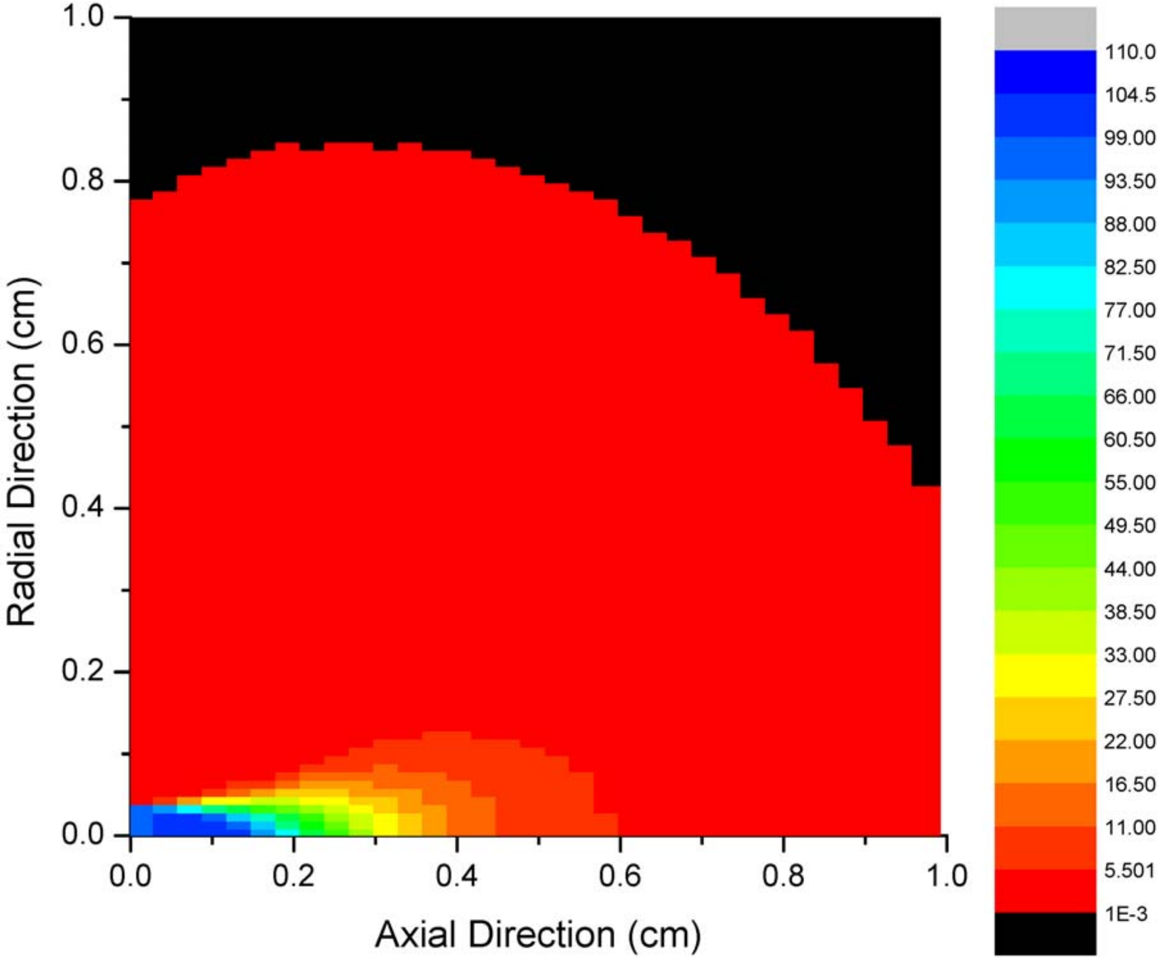
5 mm x 10 mm nozzle

# *Picture of liquid-lithium jet*



5-mm x 10-mm liquid-lithium jet flowing at 10 m/s in vacuum
(5-mm wide in this view)

# 1-MeV Electron Beam Heating




Power density in MeV/cm3 per electron

40-kW electron beam Simulates both power density and total power of 400-kW U beam.

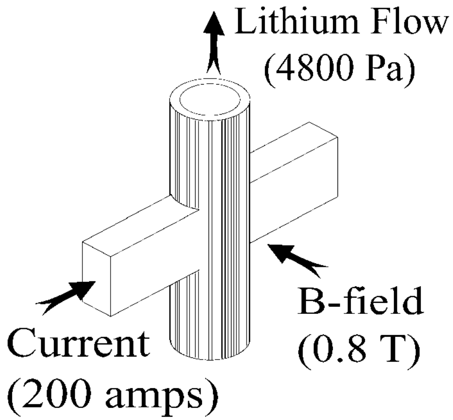
Simulations by:
I. Gomes

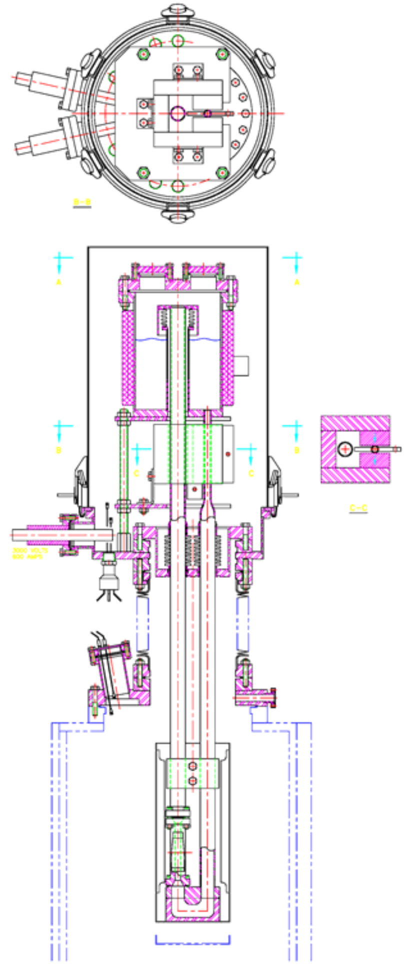
# *The 1-MeV Dynamitron being assembled*

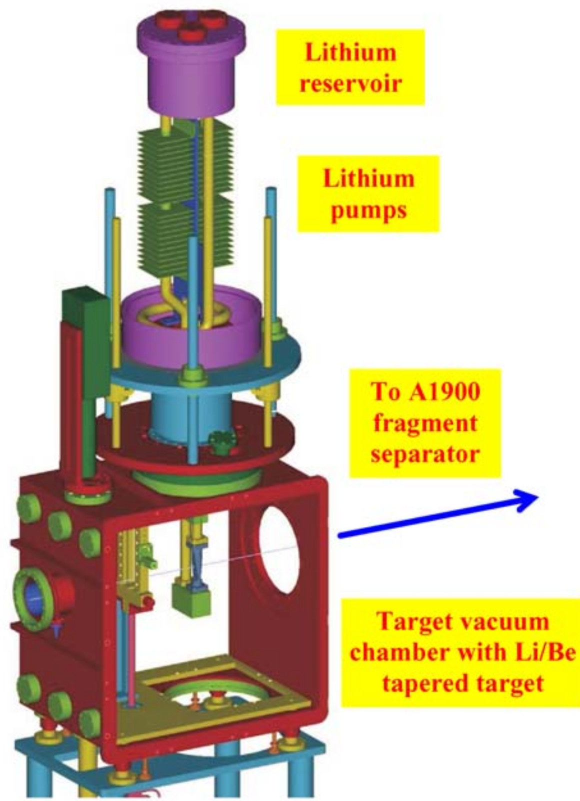
# The Liquid Lithium/Dynamitron Crew

# Re-Assembling the Liquid-Lithium Loop

# *Hybrid Be/Li Target for 4-kW Heavy-ion Beams*

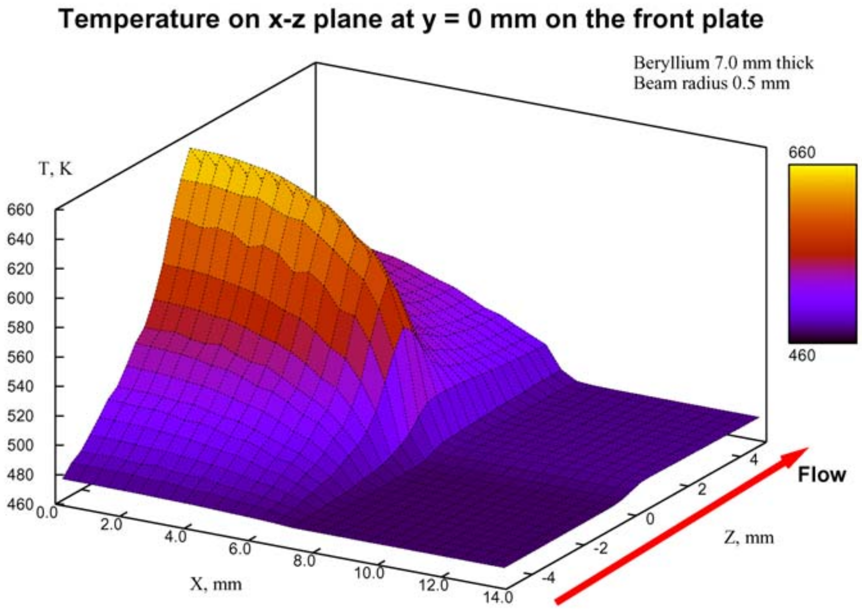


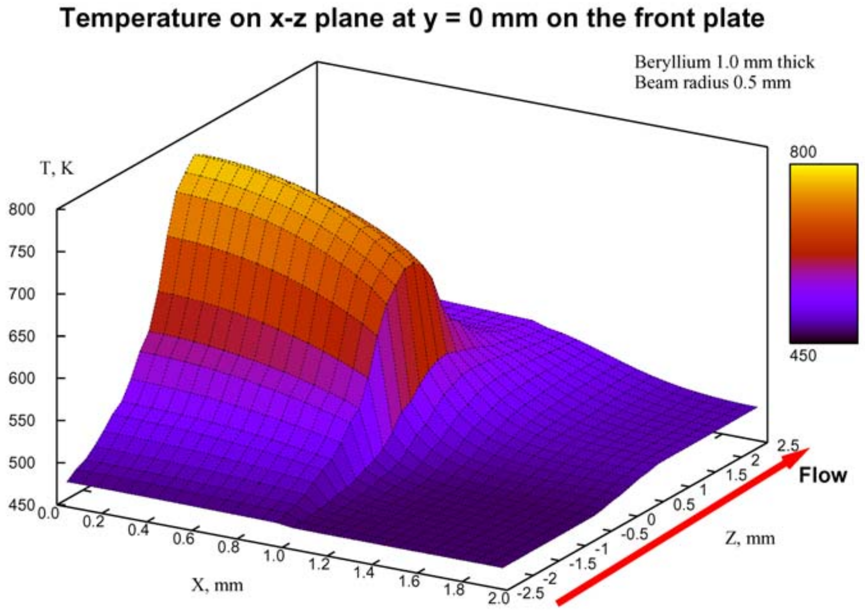






**An ANL/MSU collaboration for use at NSCL**

# *Heating of windows by oxygen & calcium beams*



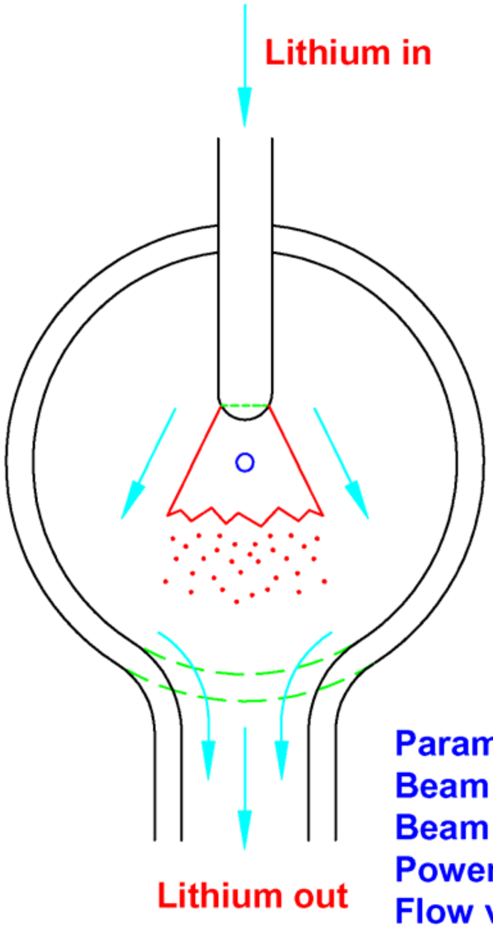

**Simulations by A. Hassanein**

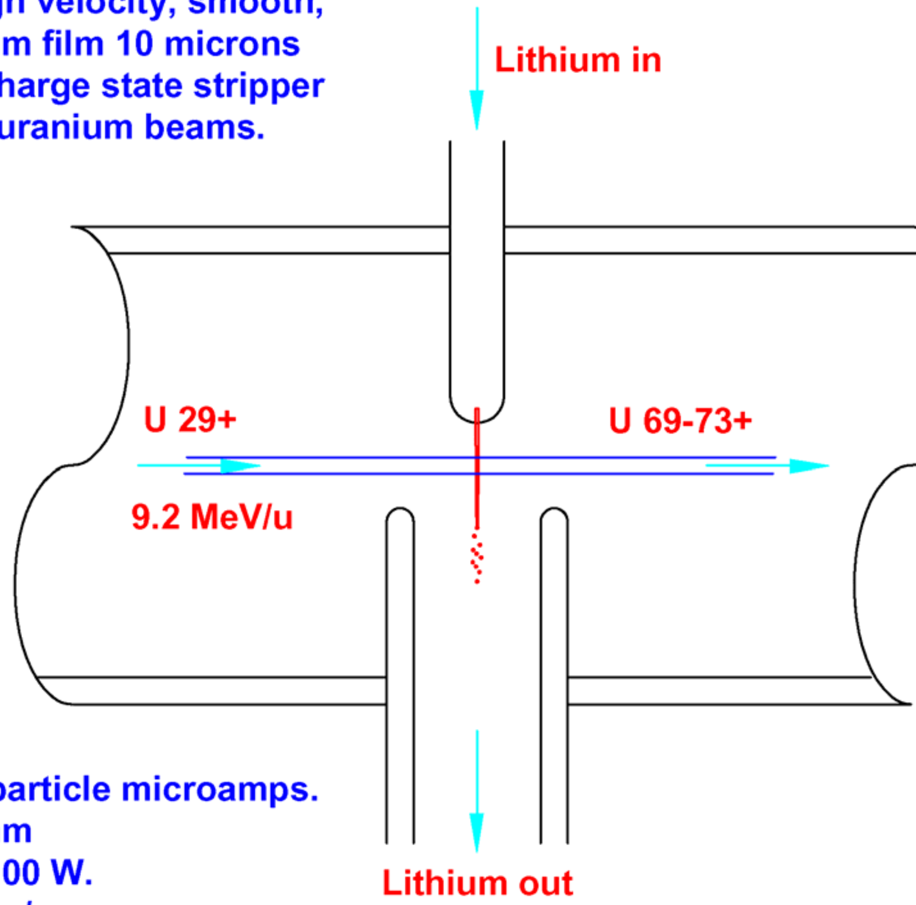
**Three-dimensional thermal calculation of the temperature distribution in the beryllium window and flowing lithium for the case of a 200 MeV/u $^{16}O$ beam at an intensity of 1 particle microampere. The peak temperature is at the outside surface of the beryllium and is 660 K.**

**Three-dimensional thermal calculation of the temperature distribution in the beryllium window and flowing lithium for the case of a 160 MeV/u $^{48}Ca$ beam at an intensity of 0.5 particle microampere. The peak temperature is at the outside surface of the beryllium and is 800 K.**

# *Concept for Thin Liquid Lithium Stripper Film*

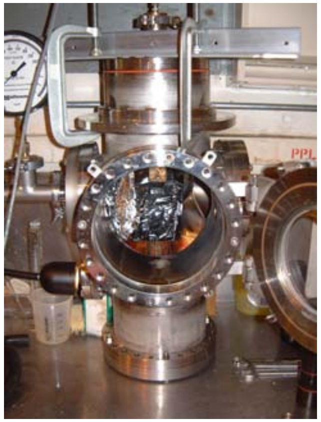
**Problem:**
**Develop high velocity, smooth, stable lithium film 10 microns thick as a charge state stripper for intense uranium beams.**

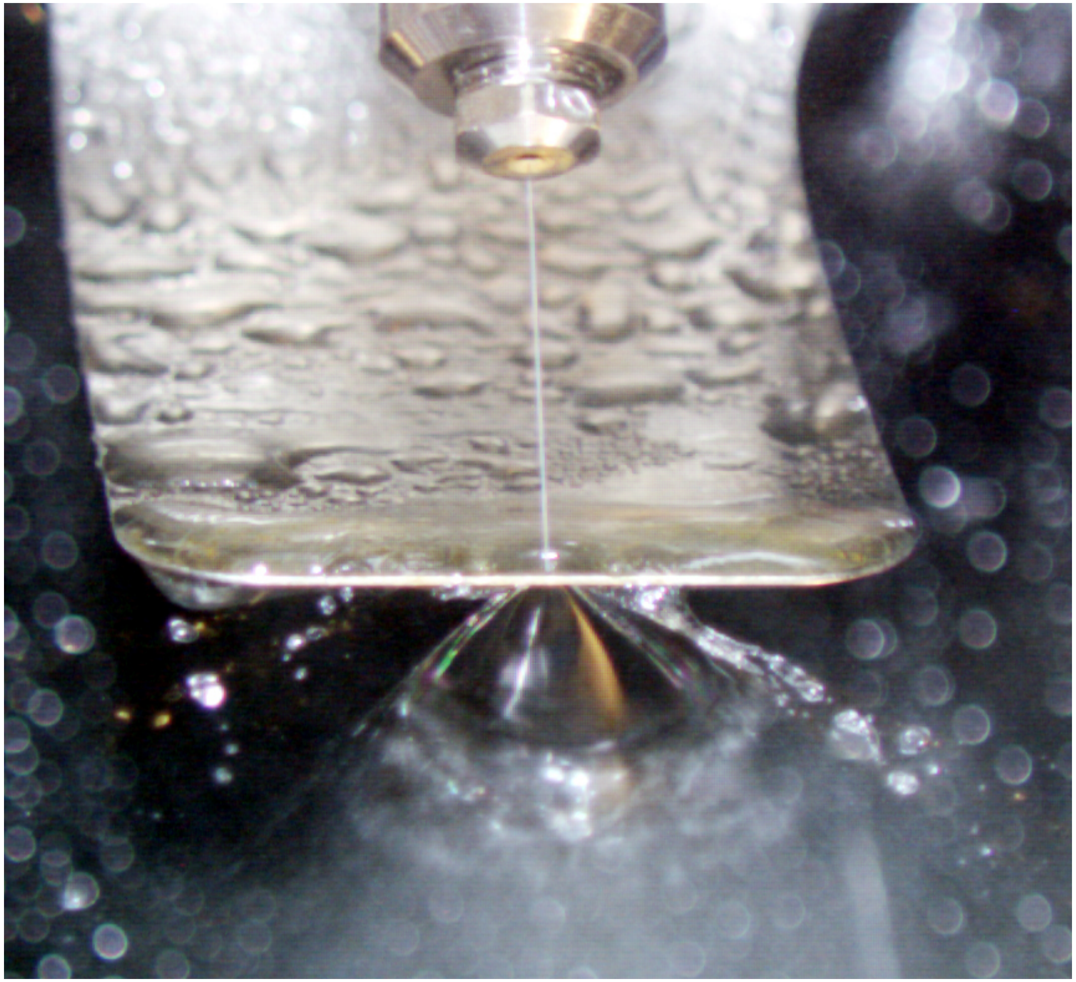



**Parameters:**
**Beam current: 1.5 particle microamps.**
**Beam diameter 1 mm**
**Power deposited: 100 W.**
**Flow velocity: ~30 m/s.**
**Peak temperature rise: ~200 C.**

# RIA Thin Film Strippers



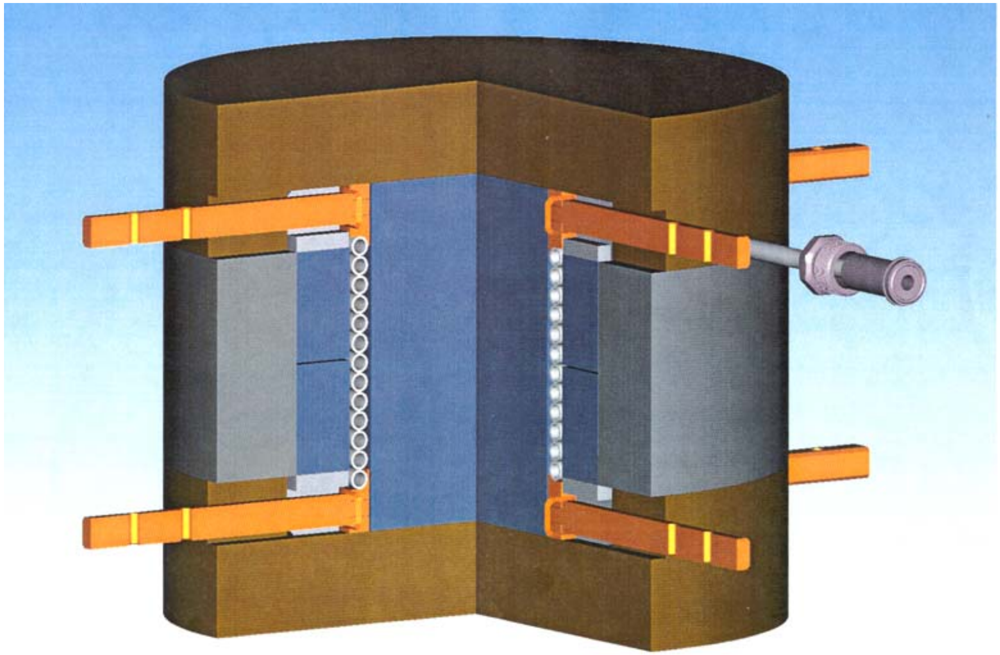


**To date:**

- **Water film**
- **0.25 mm diameter orifice**
- **33 m/s jet velocity**
- **15 atmospheres driving pressure**
- **>2 micron film thickness**
- **Under partial vacuum**
- **Film area ~ 1 cm diameter**

# RIA Thin Film Stripper Pump Progress

- **RIA Thin Film Stripper Pump Design**
  - DC EM Pump
  - Low flow
  - High discharge pressure



**Based on pump developed by R. Smither at the APS**

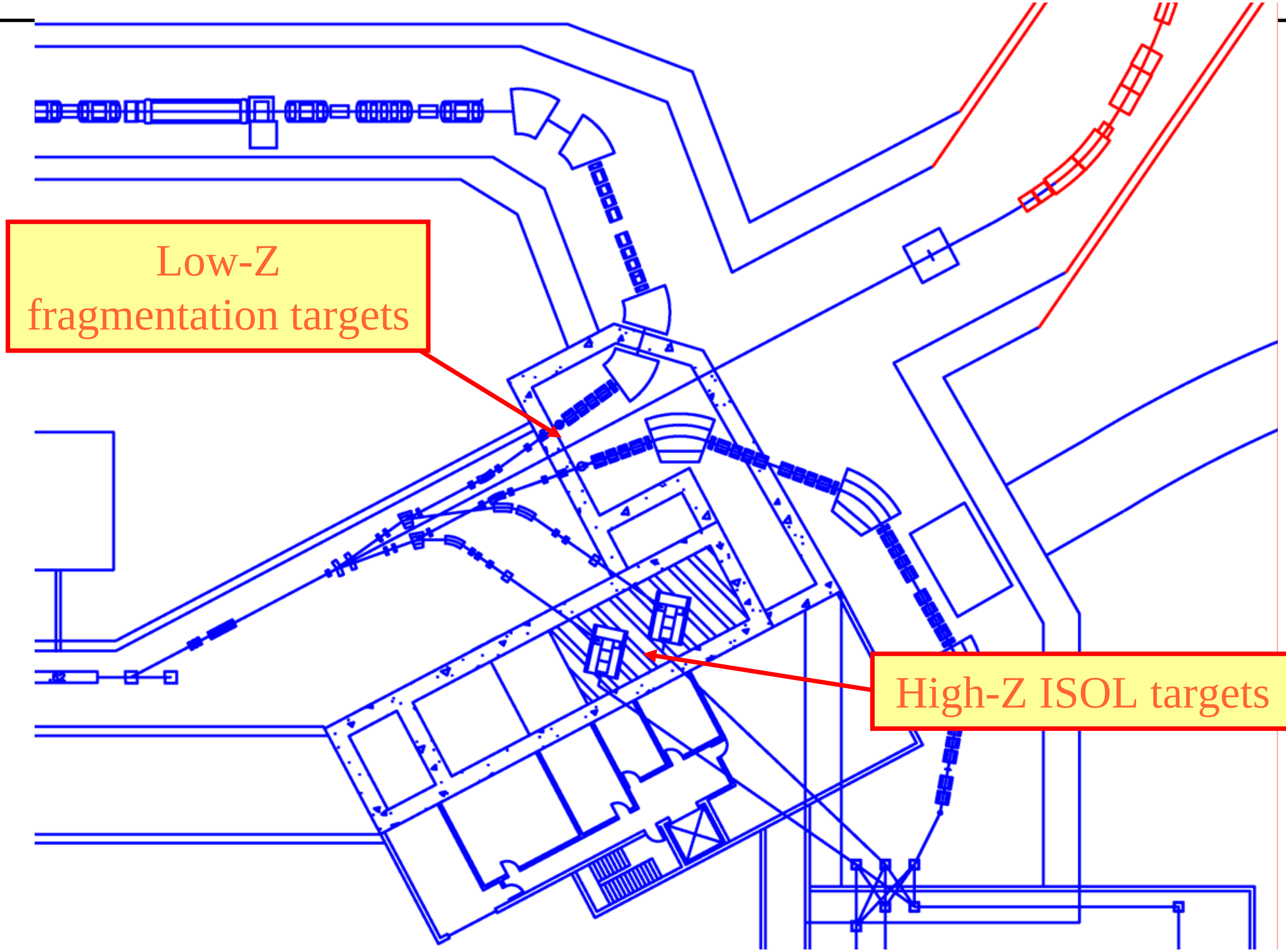
# Status

- **Liquid Metal Systems for High Power Accelerators**
  - Targets---Look very promising, 40kW beam on target in 9/03
  - Thin Film Strippers---development underway
- **Technical Issues**
  - Engineering---well understood
  - Thermalhydraulics---well understood
  - Liquid metal pumps ---unique pump required for Li stripper
- **Alkali Metal Safety Issues**
  - Alkali metal handling---well understood
  - Fire protection---well understood
  - Waste treatment & disposal---well understood

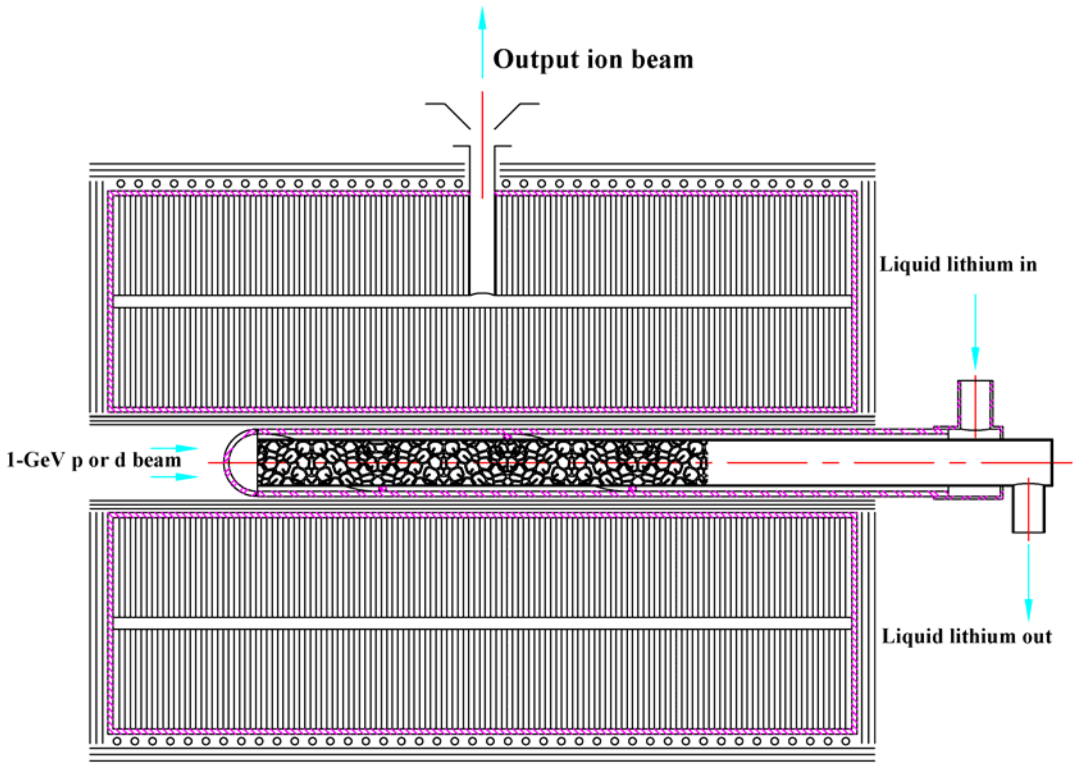
# *Needs for future work*

- **Lithium Target**
  - From e-beam tests: collect data for Safety Analysis operating envelope
- **Lithium thin film stripper**
  - High temperature, high pressure pump development [first half of FY2004].
  - Build thin film test stand [first half of FY2004].
  - Film production and stability [second half of FY 2004].
  - Nozzle design and erosion resistance [second half of FY2004].
  - Lithium purification and chemistry control [FY2004].
  - Average film thickness [second half of FY2004].
  - Film thickness variations [FY2005].
  - Lithium velocity distributions [FY2005].
  - Studies of film stability at equivalent uranium beam power density [FY2005].

# Production Target Areas and Beam Sharing



# Two-step, n-generator target concept



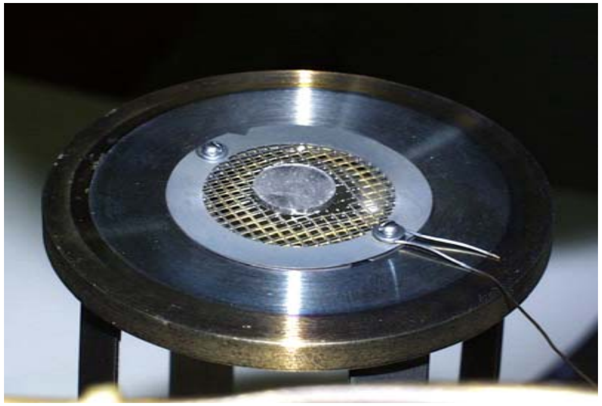

Prototype being developed by W. Talbert, et al., TechSource, Inc. (SBIR Grant)
Fine-grained, higher thermal conductivity UC being developed at ANL.

# Thermal Conductivity Measurements

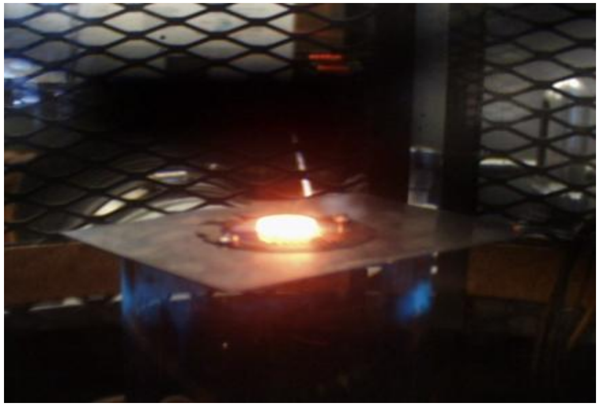
- **Sample Pellets of Uranium Carbide (10 mm ∅)**

| Sample | Density (g/cc) |
|---|---|
| 1 | 5.47 |
| 2 | 5.29 |
| 3 | 5.21 |
| | |
| UC2 + C (8:1) | 4.92 |
| | |
| I (broken) | |
| II | 4.97 |
| III | 4.78 |
| IV | 5.06 |
| | |
| UC0130A | 5.82 |
| UC0130B | 4.91 |
| UC0130C | 5.70 |
| | |
| UC/C0130A | 5.31 |
| UC/C0130B | 5.29 |
| UC/C0130C | 4.49 |
| | |
| UC/0128A | 5.21 |
| UC/0128B | 4.81 |
| | |
| UC/C/ALB02/21 A | 5.28 |
| B | 4.95 |
| C | 5.25 |
| | |
| UC/C/ALB05/07 A | 5.39 |

*Samples sent to ORNL for release studies at UNISOR.



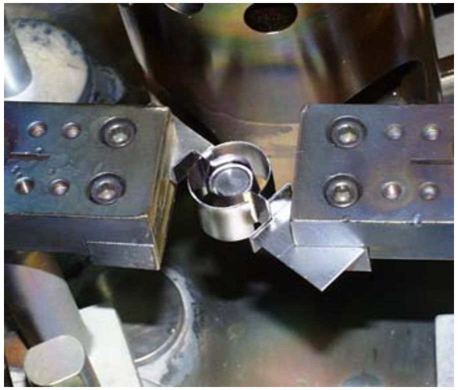
Photograph showing the uranium carbide disk above the electron beam source. Note the wire pick-up used to measure the electron beam current.



Photograph of the setup used to measure the thermal conductivity of $UC_2$. Shown is a 3/8" diameter $UC_2$ disk at approximately 1900°C supported on a Mo grid and being heated from below by the electron beam.

# Thermal Analysis - Sintering

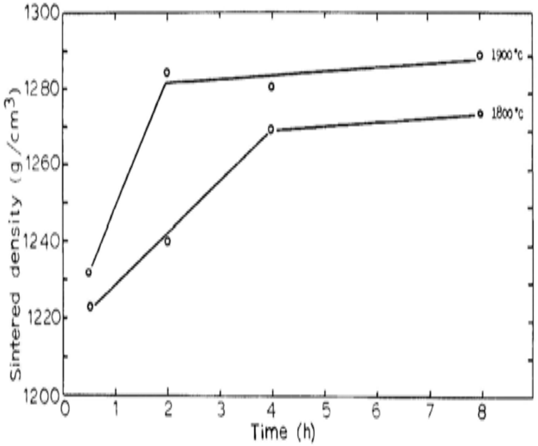
What happens at extended high temperatures?



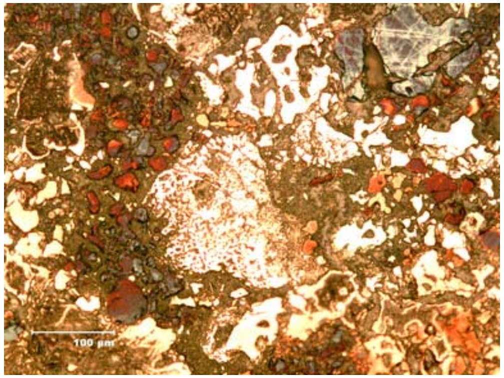
**Sample for sintering within vacuum evaporator.**

**Sample being sintered in Ta crucible under vacuum.**

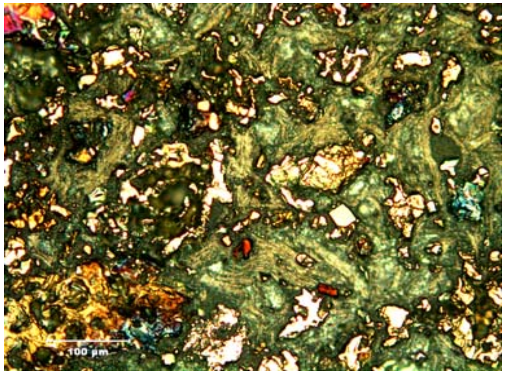
Density vs. Sintering Time



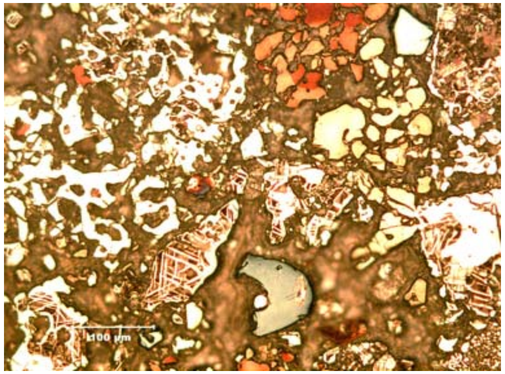

**Ref. M.H. Rand and O. Kubaschewski, (Harwell) Report AERE-R 3487**




**Before Annealing**




**Annealing at 1100$^0$C**




**Annealing at 2000$^0$C**

- **Microstructure of $UC_2$ samples prepared from powder (-60 mesh), graphite powder and albumin binder. (200x)**

# Rapid diffusion of short-lived Ar isotopes from fine-grained, full-density graphite

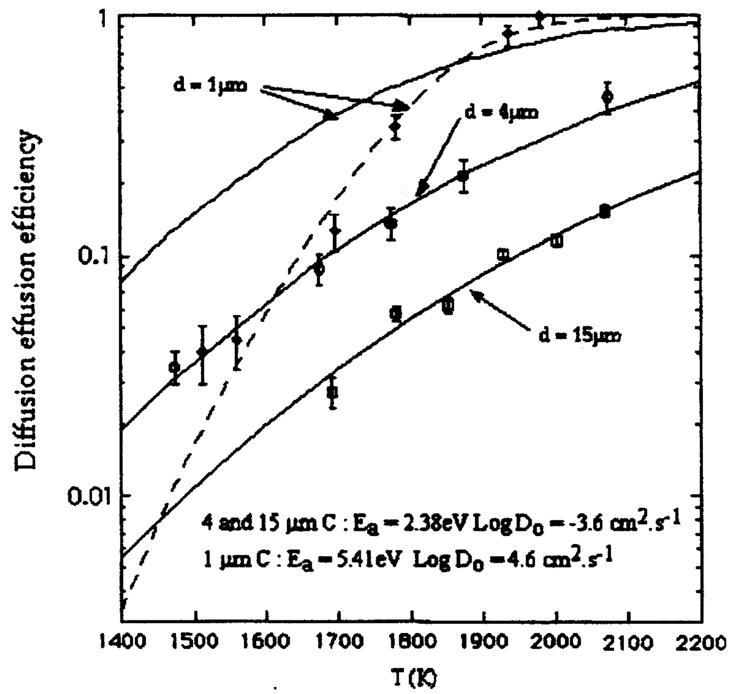



Fig. 1. Diffusion effusion efficiency as a function of the target temperature for $^{35}Ar$

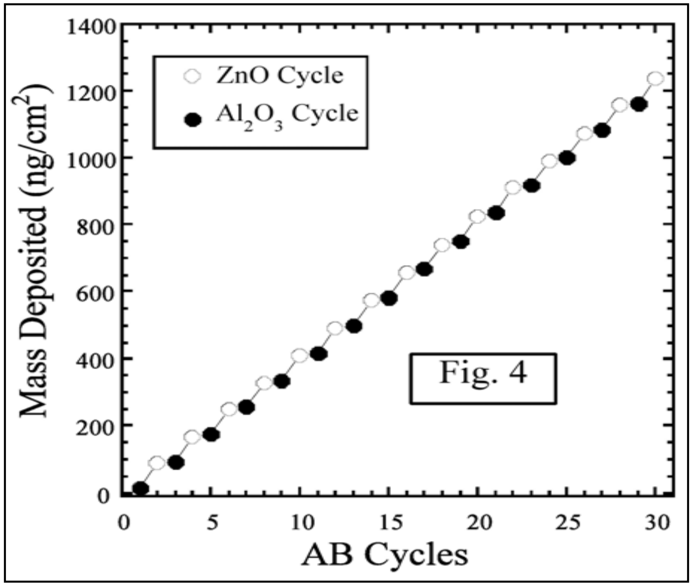
Table 1
Production yield obtained at the detection station of the SIRa separator normalised to 1pμA incident beam

| Beam | Q | 4 μm | 1 μm | Beam | Q | 4 μm | 1 μm |
|---|---|---|---|---|---|---|---|
| $^{32}Ar(98ms)$ | 1+ | | 9740 | $^{34}Ar(844ms)$ | 1+ | | $4.7\ 10^7$ |
| $^{32}Ar(98ms)$ | 7+ | 300 | 2700 | $^{34}Ar(844ms)$ | 8+ | $7.9\ 10^6$ | $2.2\ 10^7$ |
| $^{33}Ar(173ms)$ | 1+ | | $5.8\ 10^5$ | $^{35}Ar(1.78s)$ | 1+ | | $2.2\ 10^9$ |
| $^{33}Ar(173ms)$ | 8+ | $1.6\ 10^5$ | $3.1\ 10^5$ | $^{35}Ar(1.78s)$ | 8+ | $3.0\ 10^8$ | $5.4\ 10^8$ |

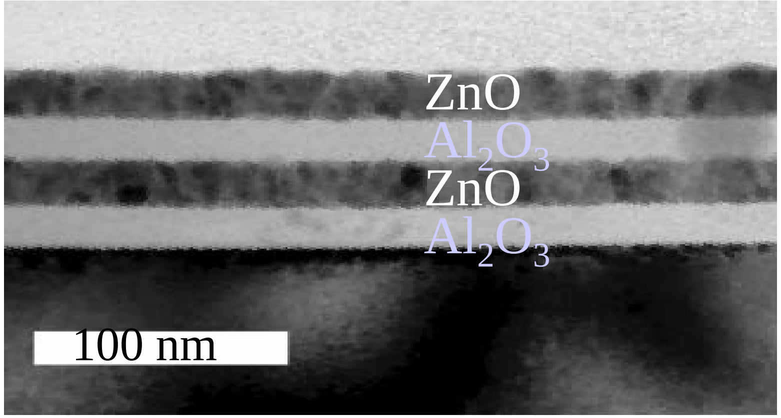
Data from the SIRa test stand at GANIL. Published in RNB-5.

# Atomic Layer Deposition (ALD)

- Working with the Material Science Division on a new deposition technique employing Chemical Vapor Deposition (CVD) onto metal (or foam) substrates using Atomic Layer Deposition – ALD.
- In this method monolayer films are grown using alternating reactive gas phases in a small furnace under computer control.
- In theory the process can be applied to uranium compounds – $UO_2$ but more promising with UN.




M.Pellin –ANL, priv. comm.




**ALTERNATE TARGET APPROACH**
12 micron Ta foil substrates
12 micron UC coating (each side)
12 micron spacing
2000 layers

# *Summary: Targets needed for RIA*

- **Very high power-density strippers**
- **Low-Z fragmentation targets for >100 kW**
- **High-Z ISOL targets for >100 kW**
- **Windowless gas targets for radioactive beam strippers and nuclear astrophysics**
- **Thin-foil targets of separated stable and radioactive isotopes**

RIA can keep target makers busy for years!