HRIBF Facility Enhancement (Driver Upgrade)

HRIBF, Upgrade for the FRIB Era

HRIBF User's Workshop

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HRIBF

U.S. DEPARTMENT OF ENERGY

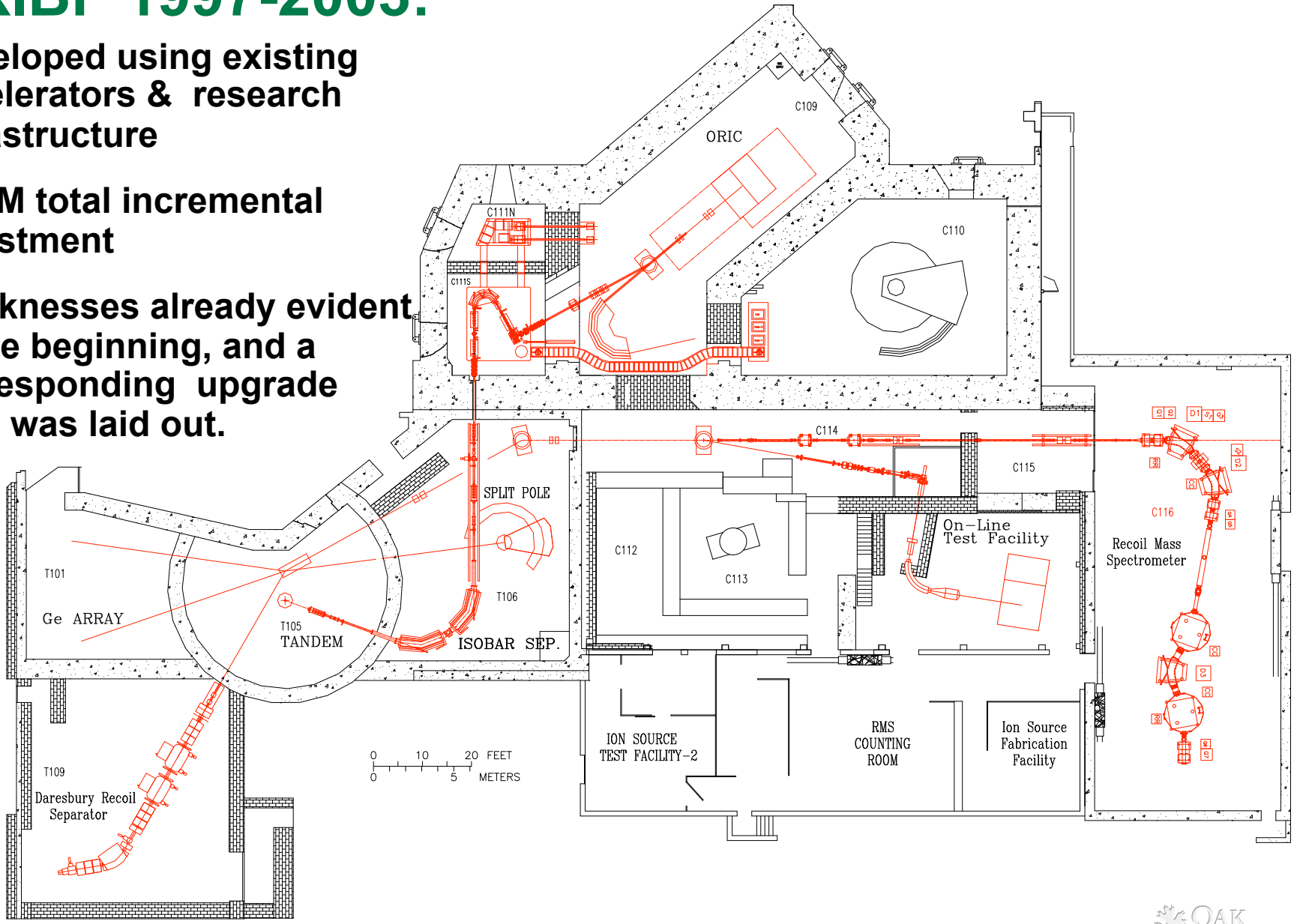
OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Brief Overview

- **This talk and the two that follow will discuss critically needed improvements to the HRIBF**
  - **I will give a brief overview of HRIBF with some historical context, and outline our view of a sensible upgrade path. Discussion of performance of the upgraded facility focuses on neutron-rich beam.**
  - **Alan Tatum will provide some technical and cost/schedule details for this upgrade path.**
  - **Dan Stracener will provide additional material on proton-rich beam development, target development, etc.**
- **Later in the program, Mike Saltmarsh will discuss the relation between this upgrade and the isotopes program.**

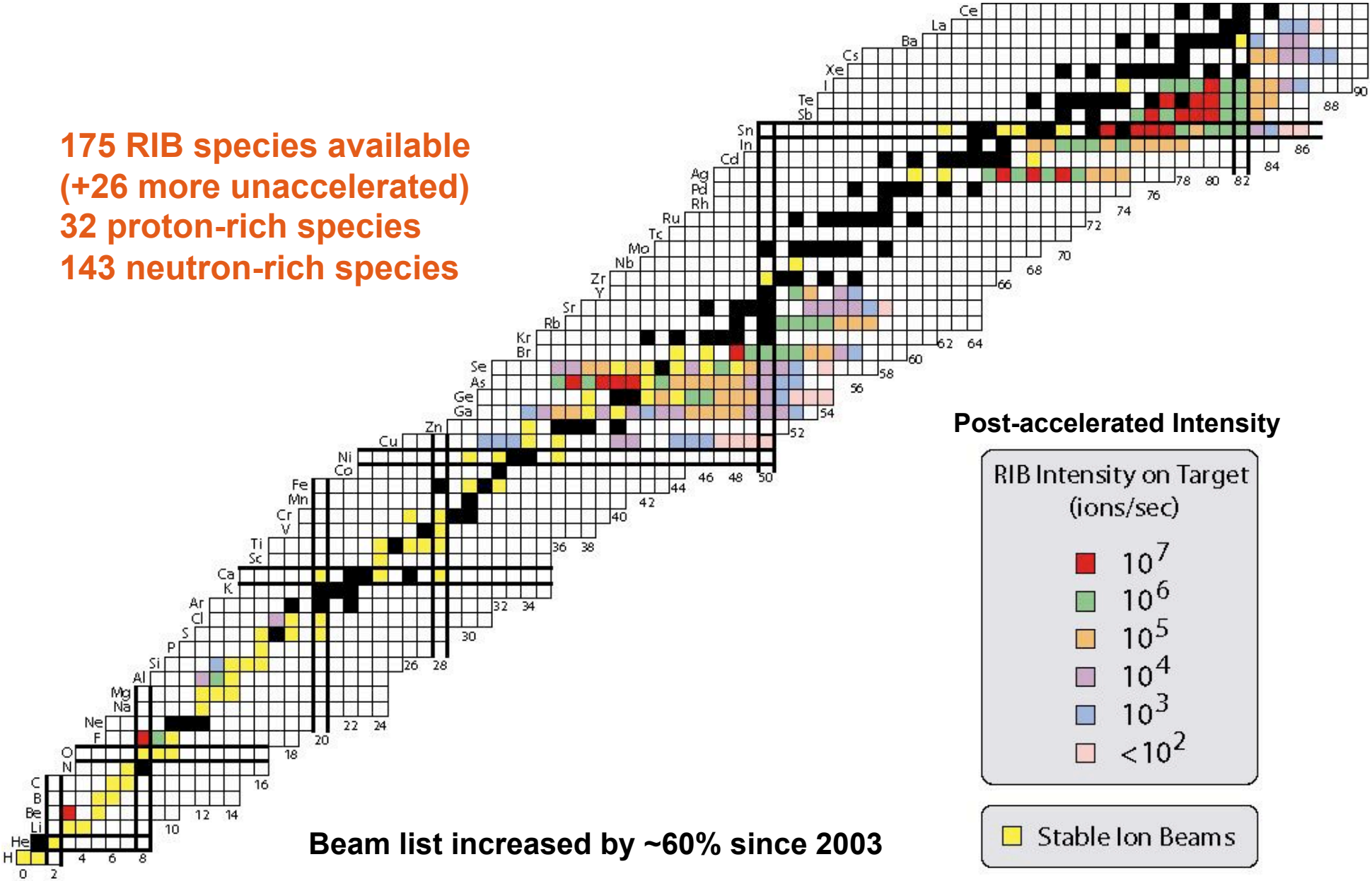
HRIBF 1997-2003:

- **Developed using existing accelerators & research infrastructure**
- **< $4M total incremental investment**
- **Weaknesses already evident at the beginning, and a corresponding upgrade path was laid out.**



HRIBF Post-accelerated Beams

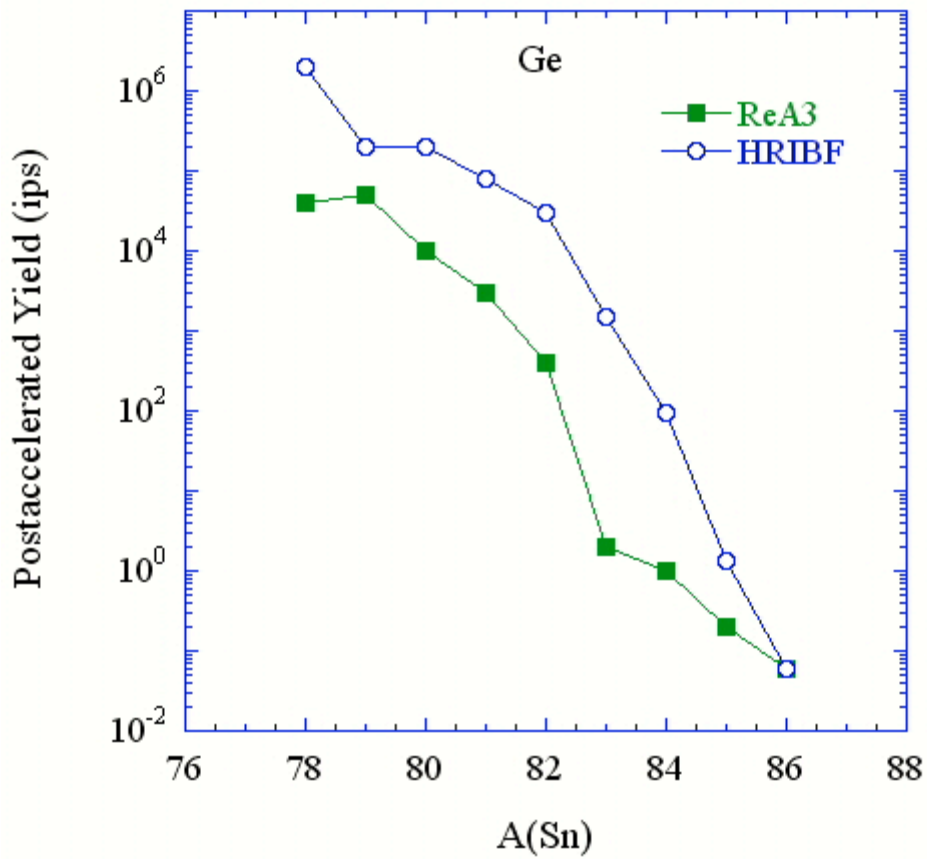
175 RIB species available
(+26 more unaccelerated)
32 proton-rich species
143 neutron-rich species

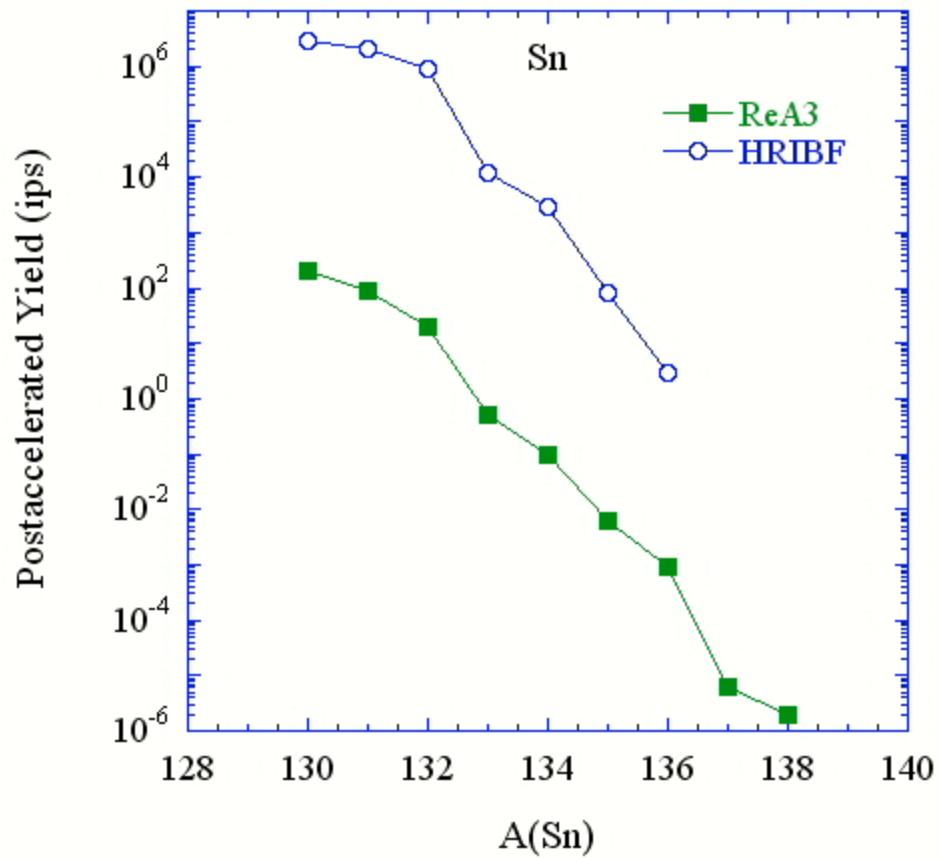


Beam list increased by ~60% since 2003

HRIBF and ReA3 at NSCL

- **Fission fragment beams post-accelerated to energies above the Coulomb barrier have been a unique HRIBF capability**
- **ReA3 will soon provide post-accelerated n-rich beams**
  - **In the near term, HRIBF will remain competitive in important regions.**



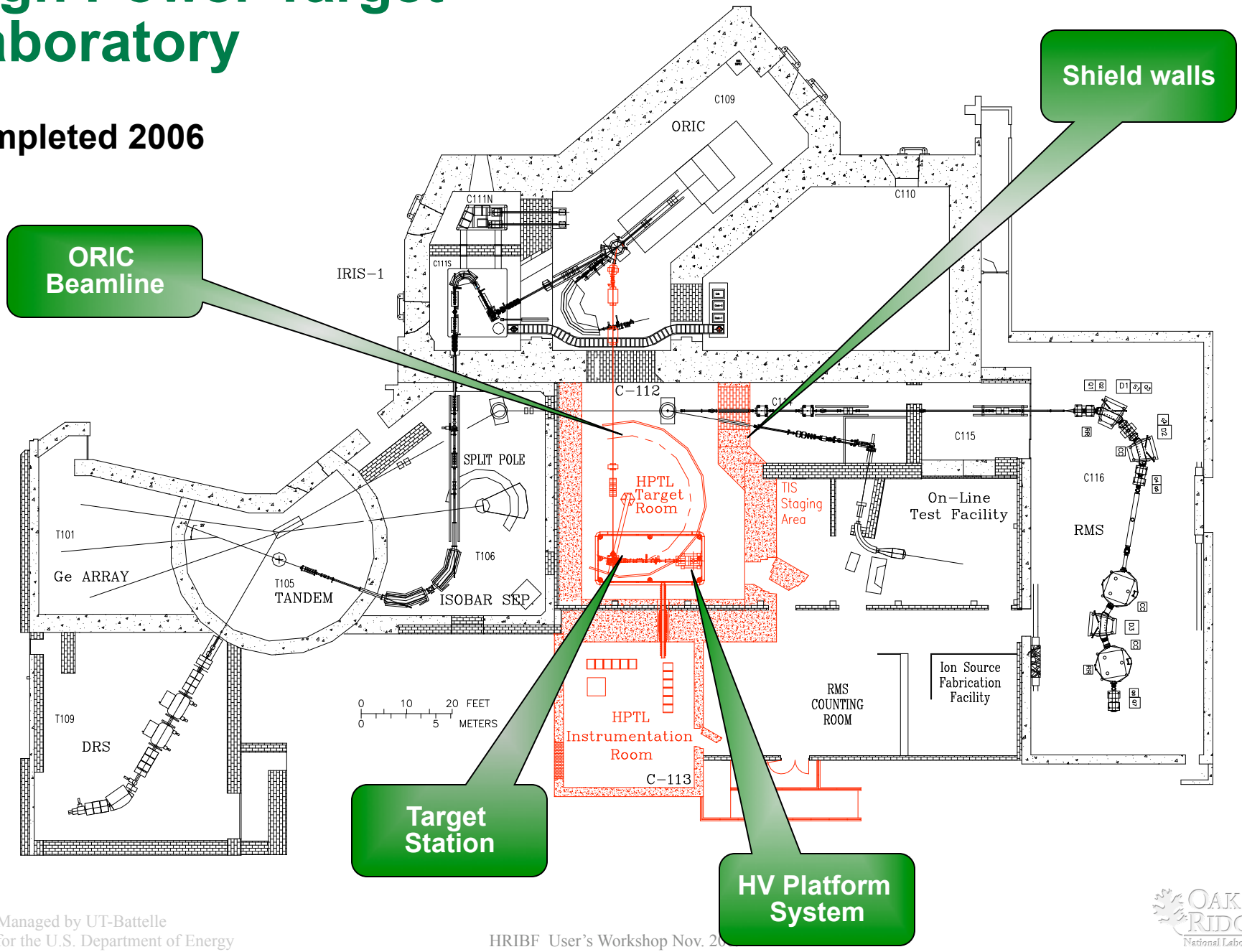


Enhancing HRIBF Performance

- HRIBF Integrated Strategic Plan (originated ~2000)
- Included :
  - New and more powerful research instruments
  - Beam development program
    - Target development and improvement
    - Beam purification techniques
    - New target systems
    - Techniques for refractory elements
  - Improve existing accelerator system reliability
  - Major production and accelerator system upgrades
    - Production system upgrade
      - HPTL / IRIS2 (2003-2009) (~$10 M)
    - Driver accelerator upgrade
    - Post accelerator upgrade

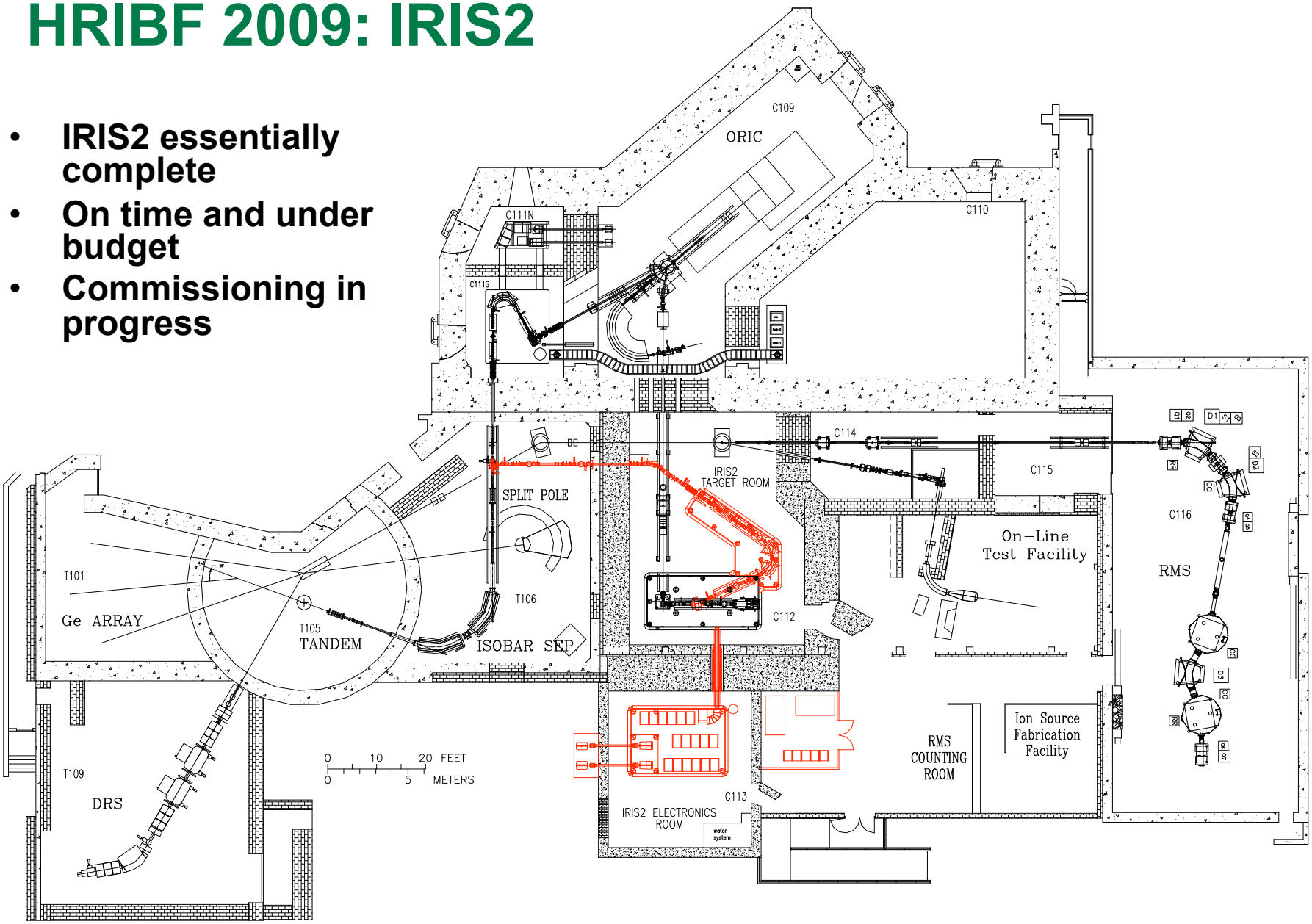
High Power Target Laboratory

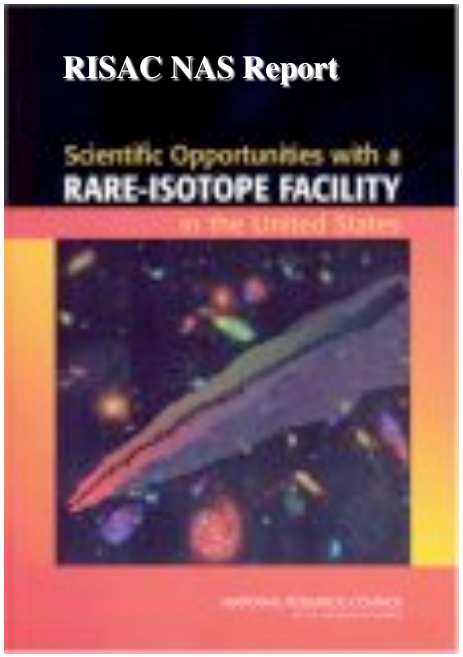
Completed 2006

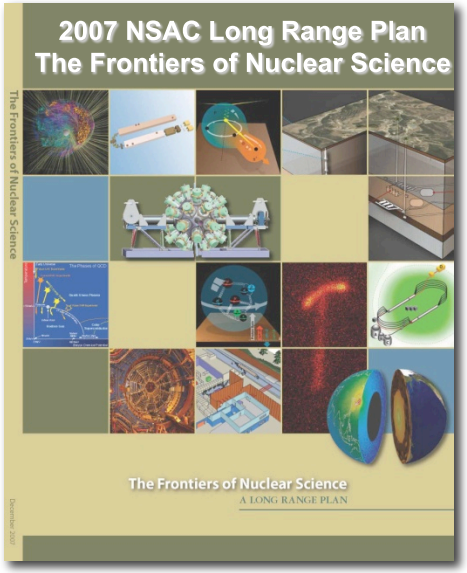


HRIBF 2009: IRIS2

- **IRIS2 essentially complete**
- **On time and under budget**
- **Commissioning in progress**







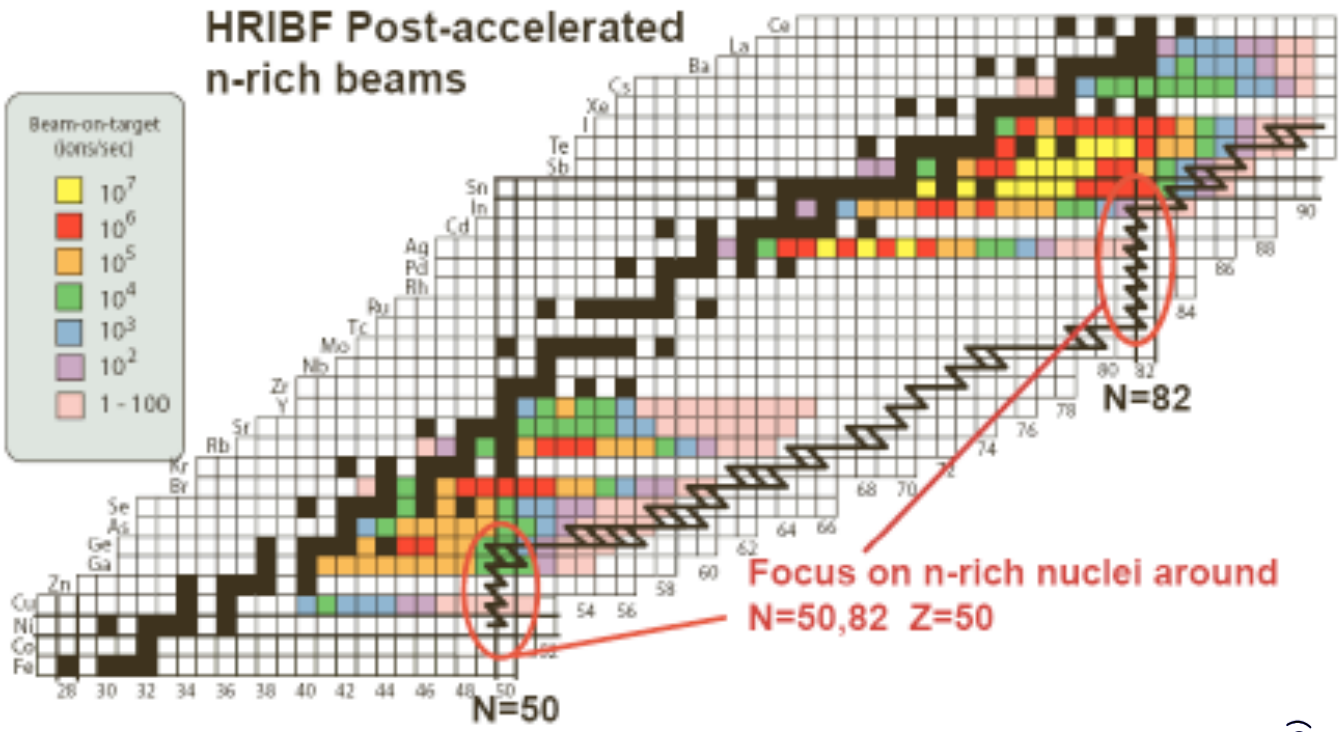
Scientific Direction

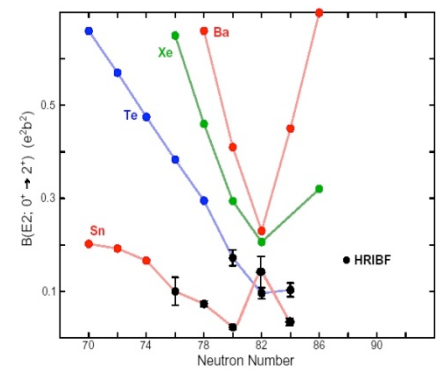
Studies of nuclei far from stability

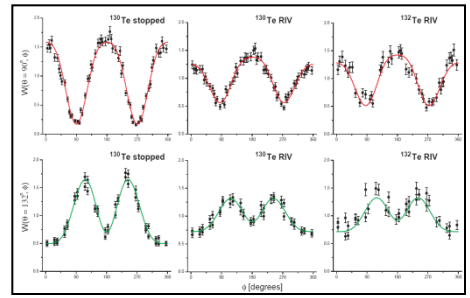
- **Nuclear Structure**
  - Probing the disappearance of shells
  - Evolution of collective motion
  - Neutron skins
  - Superheavy elements
- **Nuclear Astrophysics**
  - Origin of elements
  - Mechanisms of stellar explosions
- **Societal Applications**

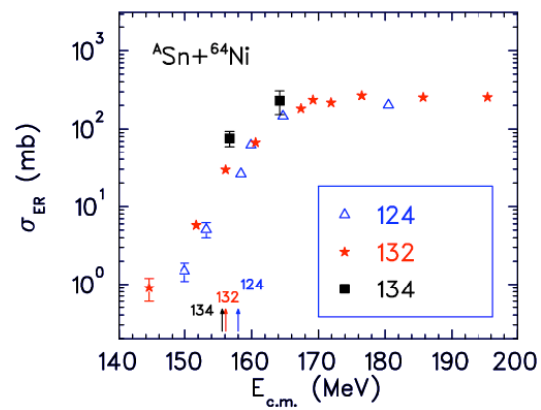
These areas will be significantly enhanced by the upgrade to be discussed here

Our niche
High quality ISOL Beams









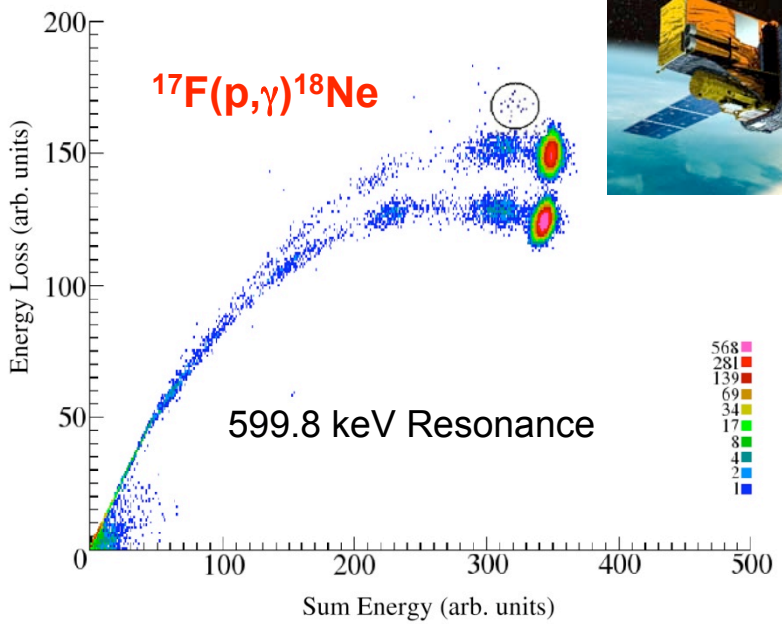
Pioneering structure and reaction studies

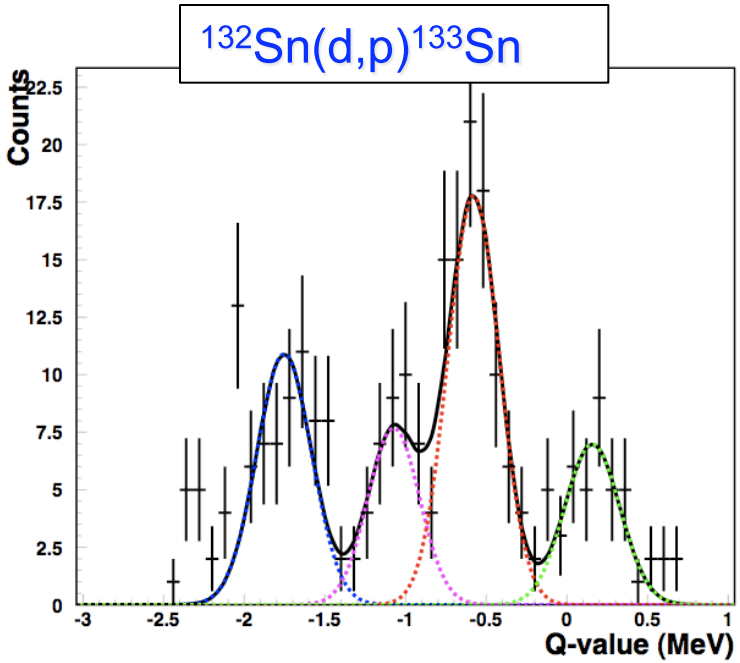
- Coulex: quadrupole collectivity around ^{132}Sn and ^{82}Ge
- Transfer: s.p. states around ^{132}Sn and ^{82}Ge with (d,p)
- g-factor measurements around ^{132}Sn
- b-decay studies around ^{78}Ni
- Fusion enhancement at sub-barrier energies in ^{132,134}Sn+^{64}Ni

Our niche
High quality ISOL Beams

Pioneering nuclear astrophysics studies with proton-rich and neutron-rich ISOL beams

- First Constraint on Very Low Temperature $^{18}F(p,\alpha)^{15}O$ reaction rate in Novae
- First $^{17}F(p,\gamma)^{18}Ne$ measurement for Novae
- Transfer: s.p. states around ^{132}Sn and ^{82}Ge with (d,p)





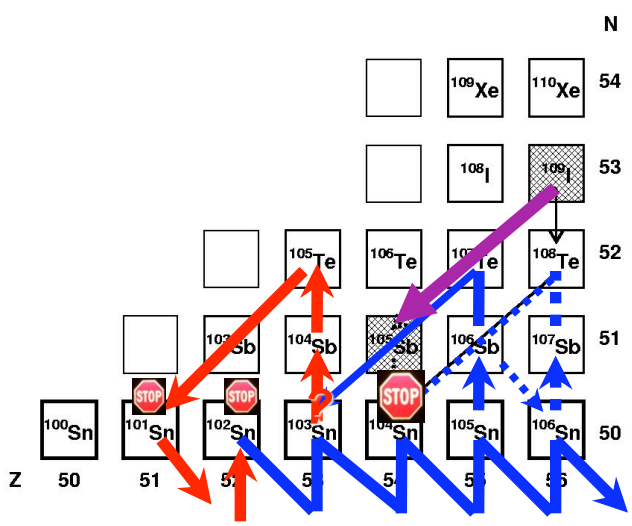
Our niche
Unique Tools for Research

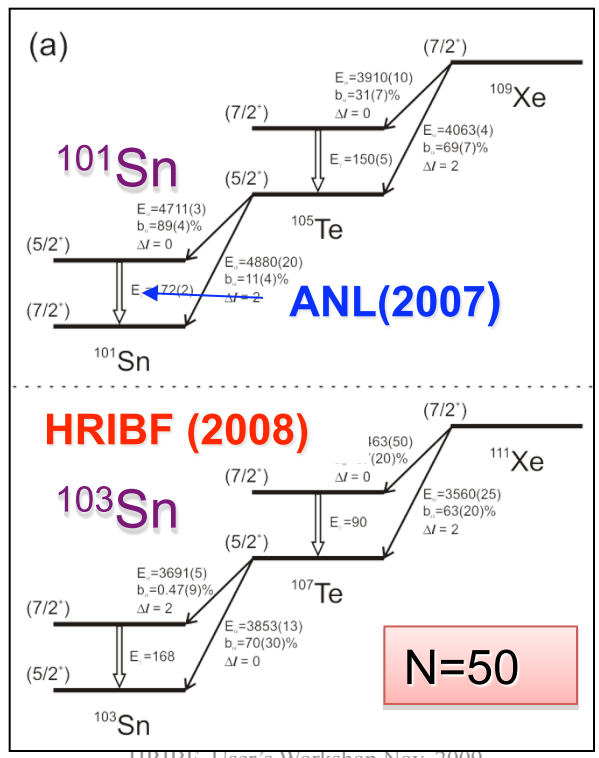
Pioneering studies in the ^{100}Sn region

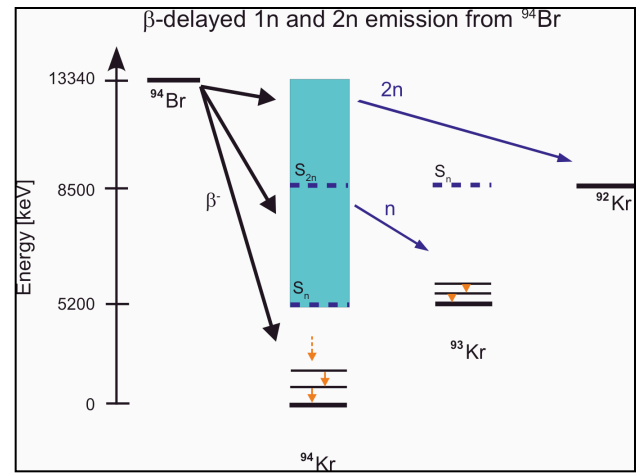
- Superallowed alpha decays and shell structure at and above ^{100}Sn
- Proton emission and rp-process termination

Applications

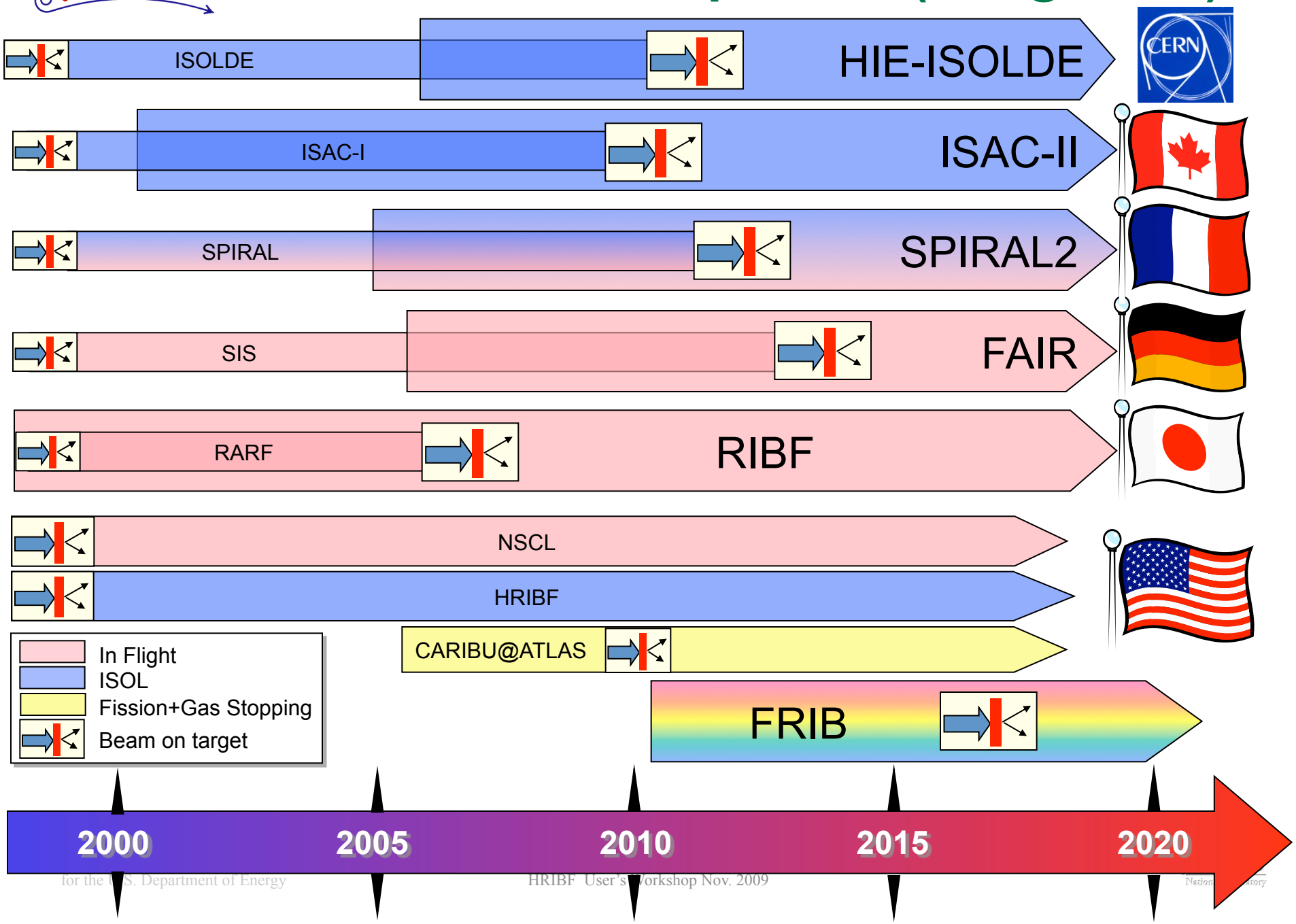
- Accelerator Mass Spectrometry
- Wear studies
- Nuclear fuel cycle







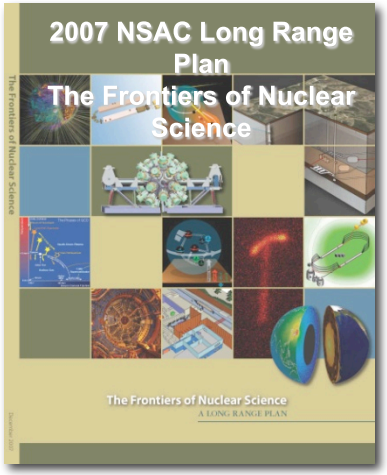
International Perspective (Long Term)



International Perspective (cont.)

- "The current U.S. program is world-leading, with the highest intensity fast exotic beams available at the NSCL and a unique set of beams from actinide targets at HRIBF."
- "Clearly, the major national user facilities in the United States (NSCL at MSU, and HRIBF at ORNL) are now competitive with the world's other leading facilities and, thus, are extremely important."
- "HRIBF has demonstrated the ability to accelerate approximately 175 radioactive isotopes including 140 neutron-rich species; more than 50 of these, including ^{132}Sn, are available at intensities of 10^6/s or greater. The post-accelerated neutron-rich beams are unique worldwide."

RISAC report



Long Range Plan 2007 and HRIBF Upgrade

There are no specific recommendations in the LRP report about upgrades of low-energy accelerator facilities; the main focus was on launching FRIB and secondary recommendations could hurt this goal. In spite of this, the Long Range Plan 2007 report does provide support for such upgrades.

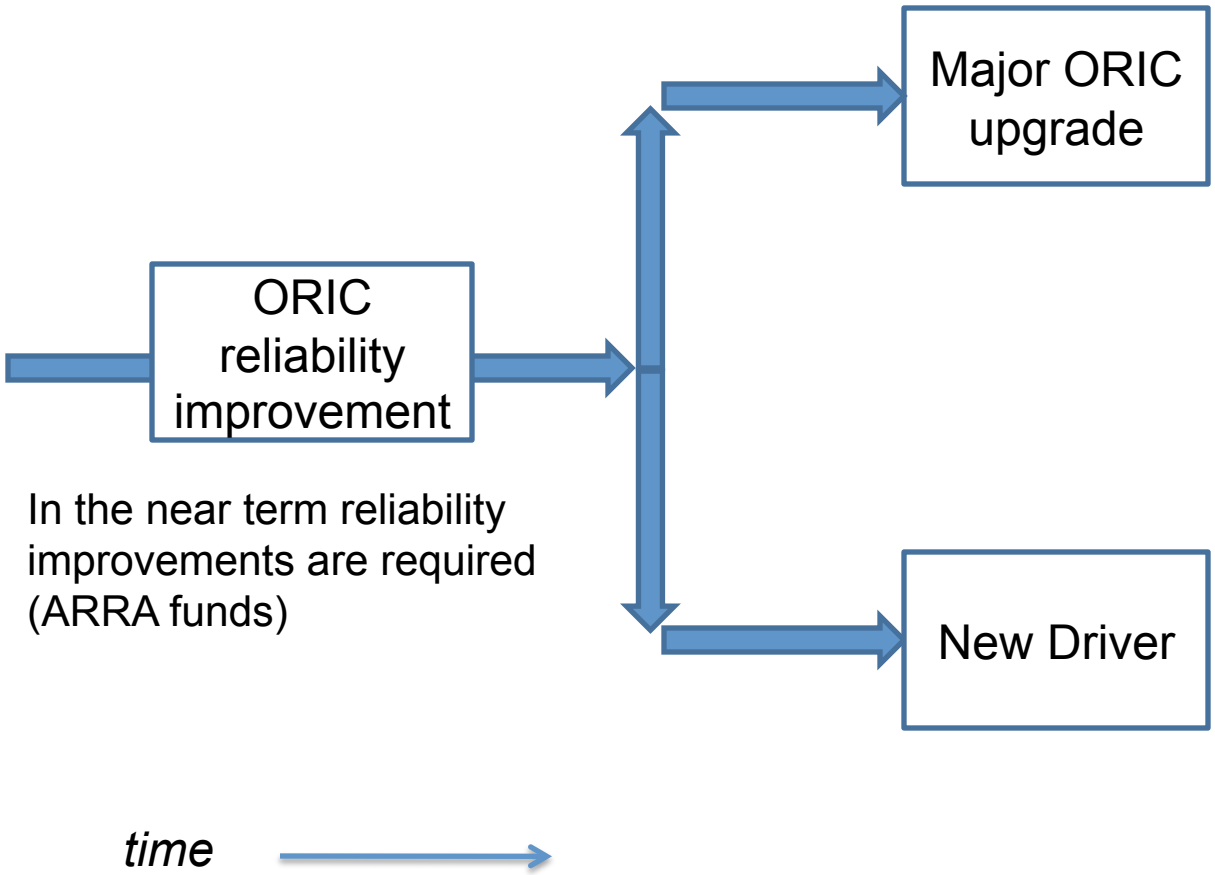
“To launch the field into this new era requires the immediate construction of FRIB with its ability to produce ground-breaking research, and effective utilization of current user facilities, NSCL, HRIBF and ATLAS.” (FRIB recommendation)

"...it is critical: (...) to optimally operate NSCL, taking advantage of its world-leading capabilities with fast rare-isotope beams; and to invest in the ATLAS and HRIBF user facilities with their unique low-energy heavy-ion and rare-isotope beams." (p. 9)

"(...) physicists have begun planning a next-generation Facility for Rare Isotope Beams (FRIB), which will deliver the highest intensity beams of rare isotopes available anywhere. But FRIB will not be available for a decade. So in the meantime, physicists hope to continue developing a comprehensive picture of atomic nuclei by strengthening operations and carrying out modest upgrades at the National User Facilities (at ANL’s ATLAS, ORNL’s HRIBF, and MSU’s NSCL)” (p.58)

Improving HRIBF Driver Performance

Basic Choice:



In the near term reliability improvements are required (ARRA funds)

Lower capital cost
Staff enhancement needed
Higher risk
More than 1 year downtime
Improved reliability
No new capability

Higher capital cost
Present staff adequate
Small risk
Smaller downtime
Much lower ops cost
Much better reliability
Major new capability

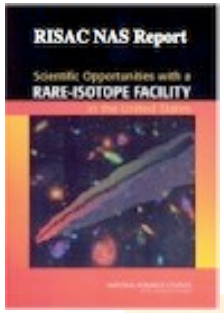
Future Science Program in a Pre-FRIB era and beyond
(Details in the Strategic Plan)

Future research at HRIBF includes studies of:

- Exotic nuclei near shell closures (such as ^{78}Ni, ^{82}Ge, ^{100}Sn, and ^{132}Sn), which have a direct bearing on the shell-model description of the nucleus and the origin of heavy elements.
- Properties of neutron-rich unstable nuclei and their reactions to find the way to synthesis of the heaviest nuclei and to improve our understanding of supernovae and red giant stars.
- Two-neutron transfer in neutron-rich nuclei: probing the particle-particle channel
- Superallowed alpha decays and cluster decays above ^{100}Sn
- Proton- and alpha-induced reactions on, and the properties of, proton-rich radioactive nuclei to understand element synthesis and energy generation in stellar explosions.
- Systematic studies of magnetic moments to explain structural changes far from stability

HRIBF's science for the benefit of society (the opportunity for advances in other scientific fields and applied technologies). Examples include:

- Accelerator Mass Spectrometry program centered around the 25-MV tandem
- Applications of radioactive isotopes in life sciences



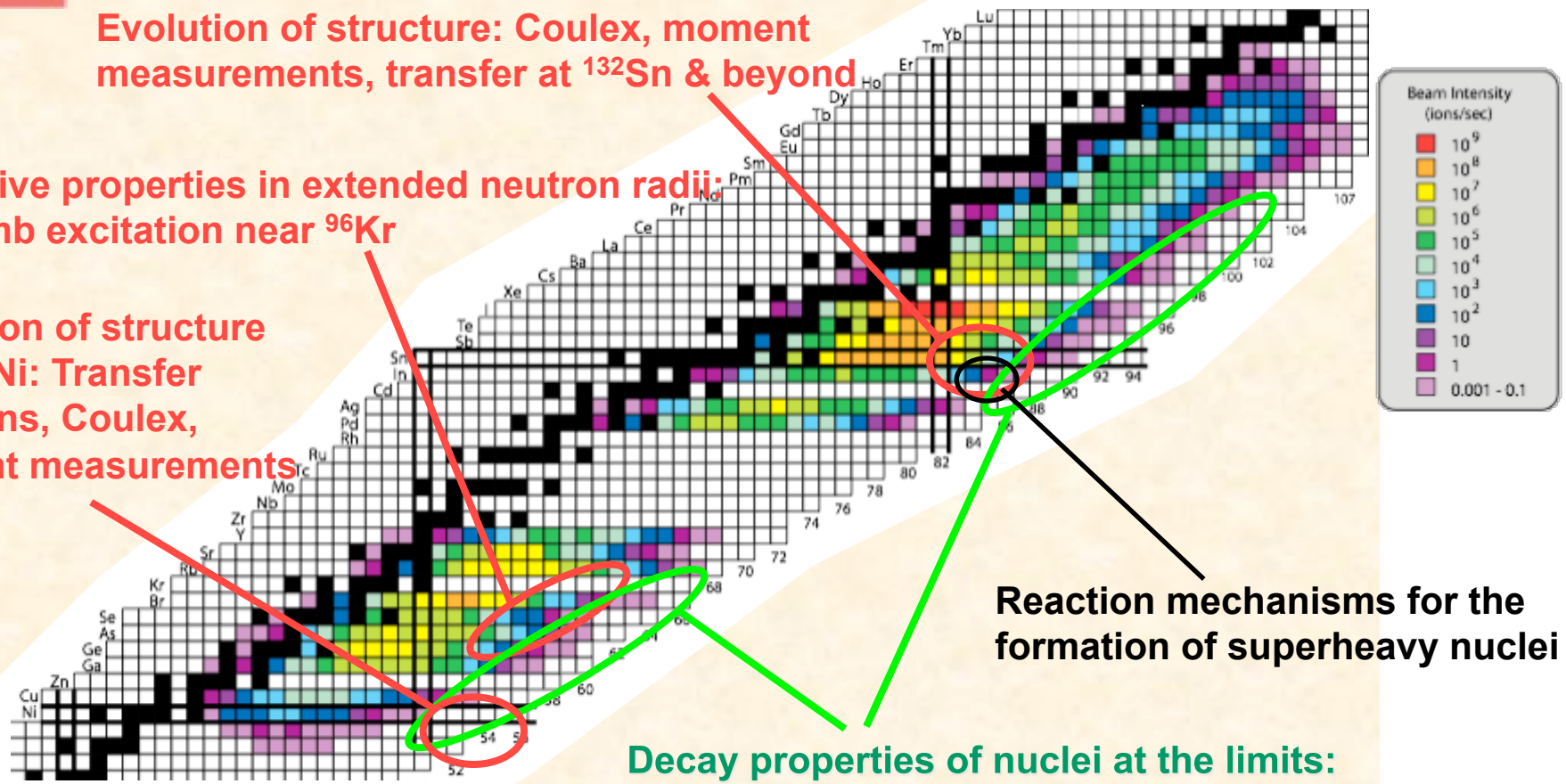
Science highlights with cyclotron upgrade

→ Will test the evolution of nuclear structure to the extremes of isospin
→ Will improve our understanding of the origins of the heavy elements

Evolution of structure: Coulex, moment measurements, transfer at ^{132}Sn & beyond

Collective properties in extended neutron radii: Coulomb excitation near ^{96}Kr

Evolution of structure near ^{78}Ni: Transfer reactions, Coulex, moment measurements



Reaction mechanisms for the formation of superheavy nuclei

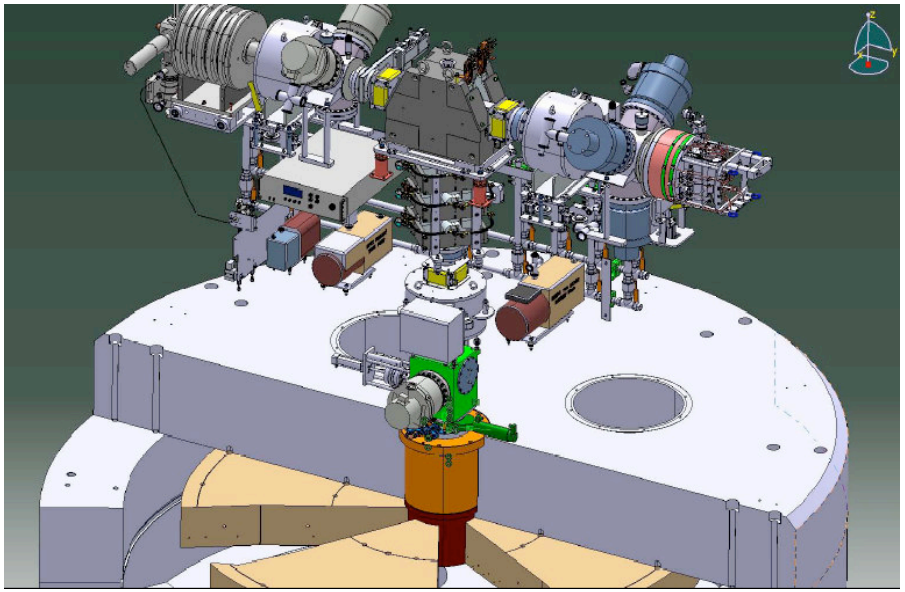
Decay properties of nuclei at the limits: Crucial for understanding the formation of elements from iron to uranium

Driver Accelerator Upgrade Proposal

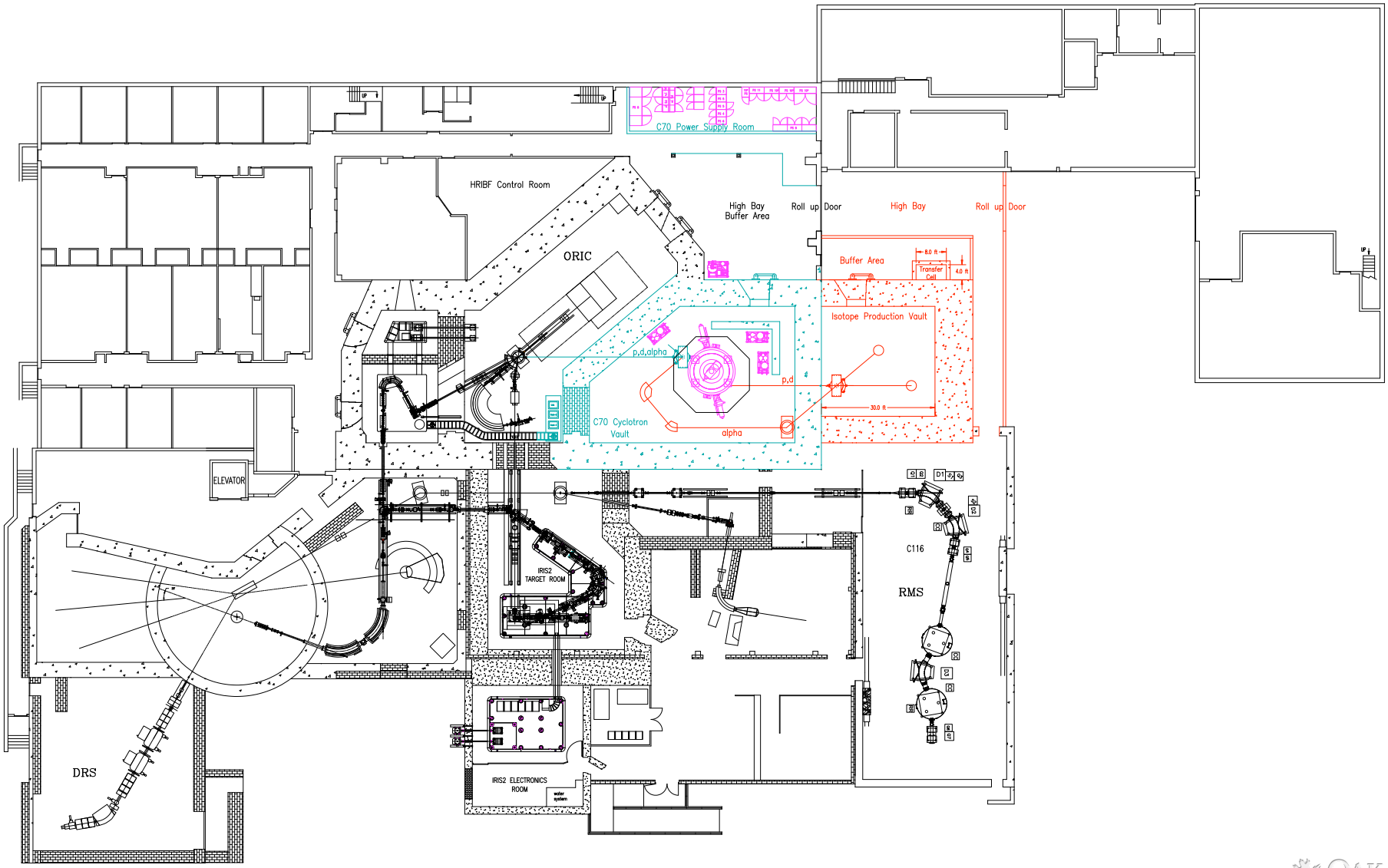
- Replace ORIC with commercial cyclotron
  - Most attractive available choice: C70 manufactured by IBA
  - Referred to in this talk as Hadron Driver Upgrade (HDU)
  - Much better performance than any ORIC improvement.
    - Large increase in RIB production rates - Greater physics reach
    - Much improved reliability
    - Lower operating cost
  - Comparison with EDU
    - Somewhat lower baseline n-rich performance
    - Better p-rich capability
    - More flexible, makes better use of existing infrastructure
    - Cost has much smaller civil construction fraction
  - Offers isotope R&D / production option together with experimental NP program (talk by Mike Saltmarsh).

Specifications (courtesy of IBA)

- **Machine Specifications**
  - **Multiple beam capability, variable E**
  - **750 µA proton, variable up to 70 MeV, dual port, H^- with foil extraction (52 kW)**
  - **>50 µA deuteron, variable up to 35 MeV, dual port, D^- with foil extraction**
  - **~50 µA alpha, fixed at 70 MeV, single port, $^4He^{2+}$ with deflector extraction**

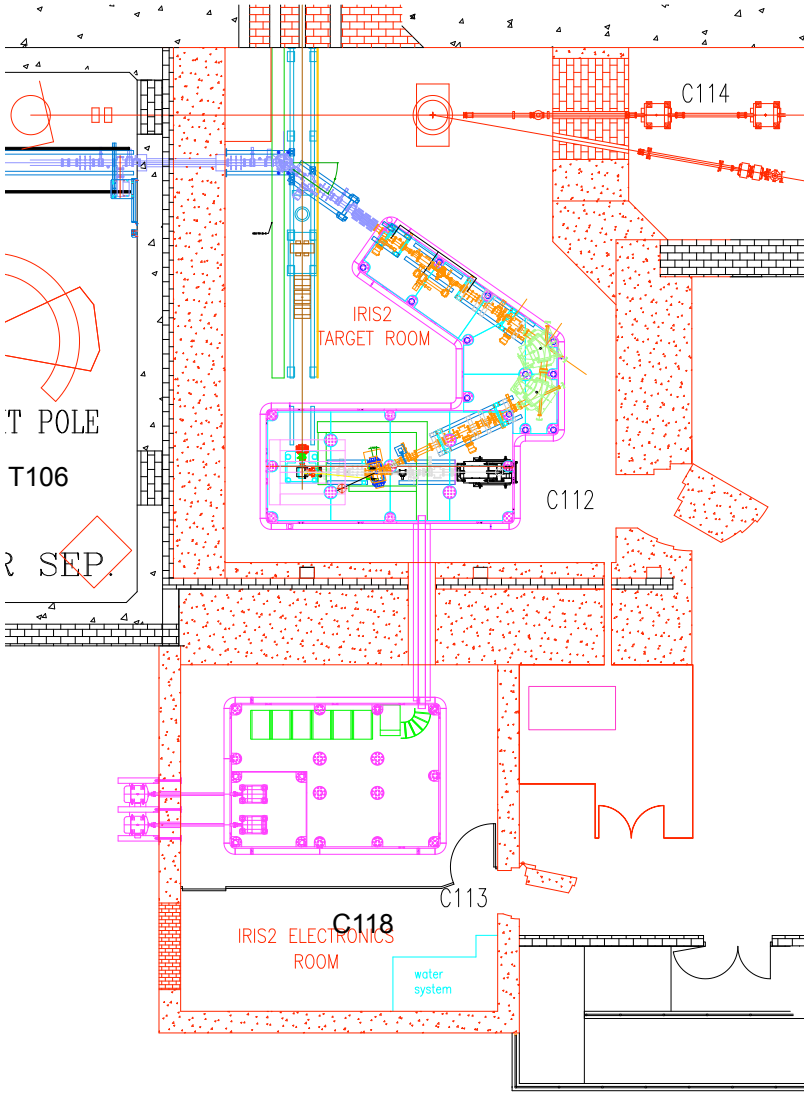


HRIBF Floor Plan Including C70



C112-C113 shielding configuration

- C112 has a simple, heavily shielded configuration.
  - More than seven feet concrete on all sides
  - Five feet concrete above
  - Nine feet concrete forward
  - Supplemented by 30 cm local shield at target
- No high occupancy space adjacent – most controlled access



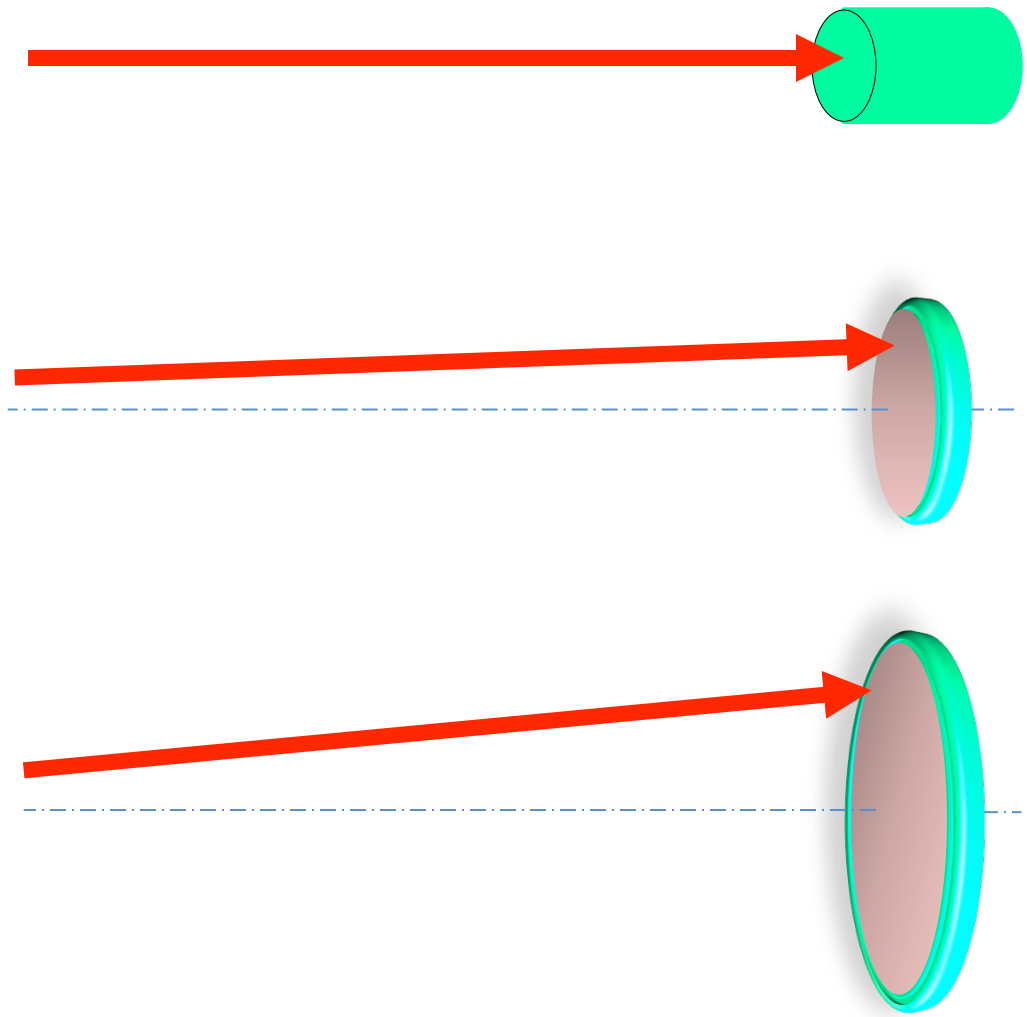
Facility Operation Plan

- Operate C70 ~6000 hours per year
- C70 can provide two extracted beams, with some limitations
  - Positive ion beam (e.g. alpha) is single user
  - Negative ion beams (H^-, D^-): two beams can be extracted
    - Relative intensity freely adjustable if both beams extracted at same energy
    - Less freedom if energies different (we await further information)
- Primary user defines beam parameters
- Deliver 4000 hr/yr RIB for experiments (as primary user)
- Deliver 1500 hr/yr (minimum)to isotopes program as primary user
  - Additional beam will be available (as secondary user) from RIB 4000 h
    - ~75% of RIB production beam used by HRIBF will be proton at maximum E
- Batch mode isotope production for HRIBF can operate parasitic ly.
- We estimate an operating cost savings of ~$850k compared to ORIC based ops providing 4000 h RIB
- No additional staff required beyond long-standing HRIBF staffing plan

Estimating Baseline HDU performance

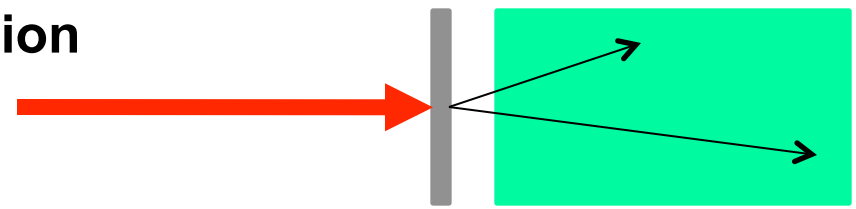
Fission fragment beams

- Present HRIBF (50 MeV):
  - About 525 W deposited in 6 g target (1.4cm x 2cm @ 2g/cm^3)
  - Power density 88 W/g
- C70 based (70 MeV p)
  - Plan to use 6 g/cm^3 UCx material
  - Large diameter targets
  - "Paint" target uniformly with beam
  - 3 cm x 1.1 cm target (47 g)
    - 82 μA for same power density
    - Total power deposited: 4.1 kW
  - 5 cm X 1.1 cm target (130 g)
    - 230 μA for same power density
    - Limit to 184 μA, so < 10 kW in target
  - Both C70 disk geometry targets have significant contributions from internal secondary neutron induced fission



Fission Fragment Beam Production
Continued

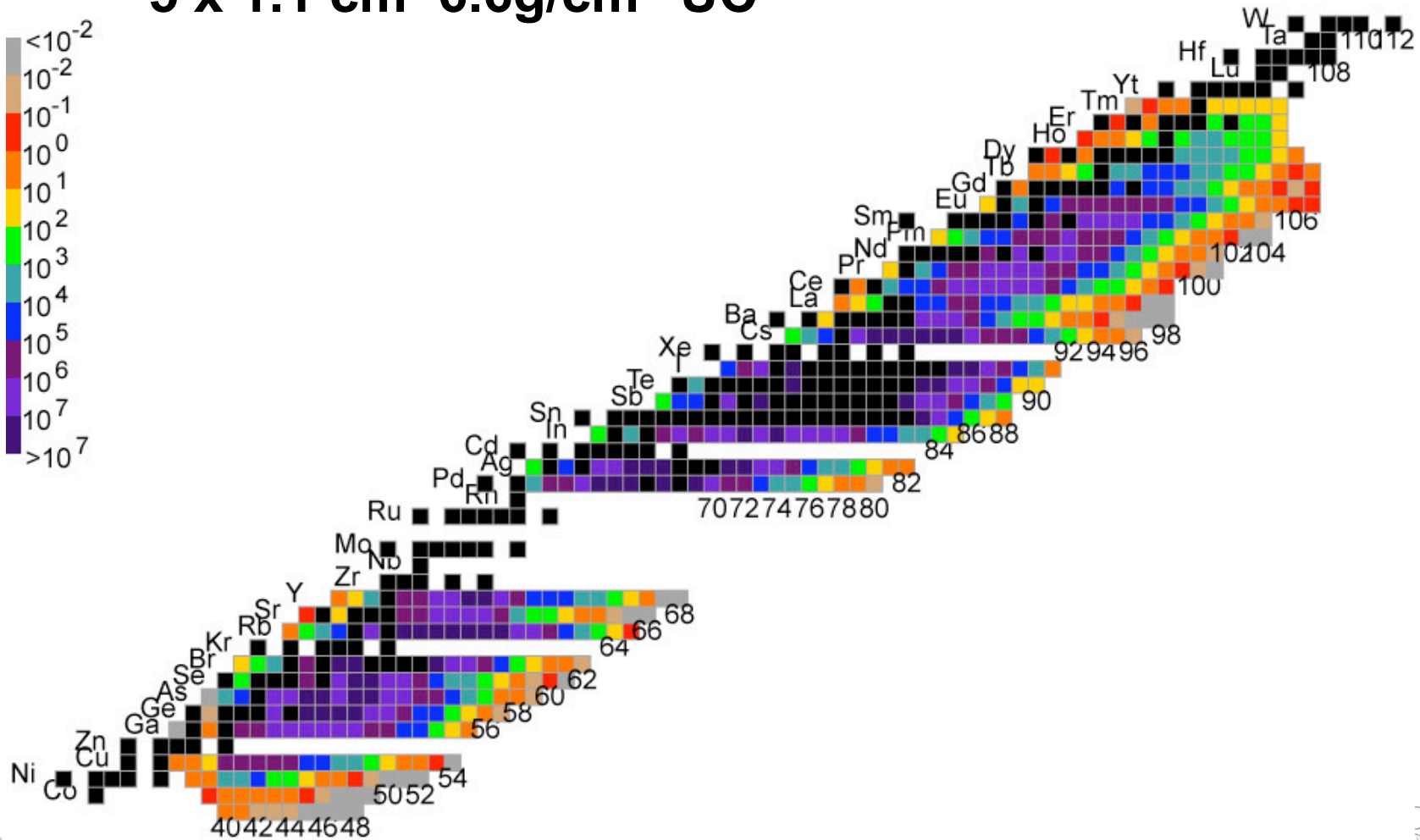
- Secondary neutron induced fission
  - C(d,n)
  - Be(p,n)
  - W(p,n)



- (p,n) should allow use of full 52 kW (750 μA) proton beam
- Neutron production target development effort required
- Modest enhancements to shielding in IRIS2 needed
- Preliminary yield calculations made with 5 cm diameter x 6 cm long, 6 g/cm^3 target.
- About 15% of Spiral-2 yield (with same fission target)
  - Spiral 2 target: 8 cm x 8 cm 11 g/cm^3
  - Nominally ~2.6 x larger fission yield than 6x6 cm 6 g/cm^3 target
- Potential for substantially increased yield for very n-rich species beyond

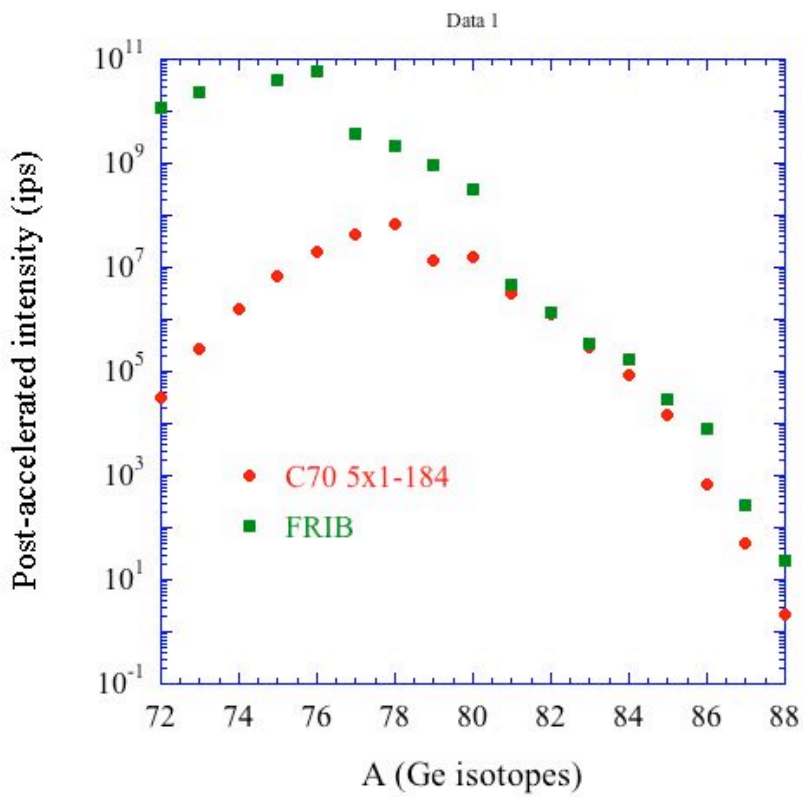
Neutron-rich post-accelerated yields from $^{238}U(p,f)$

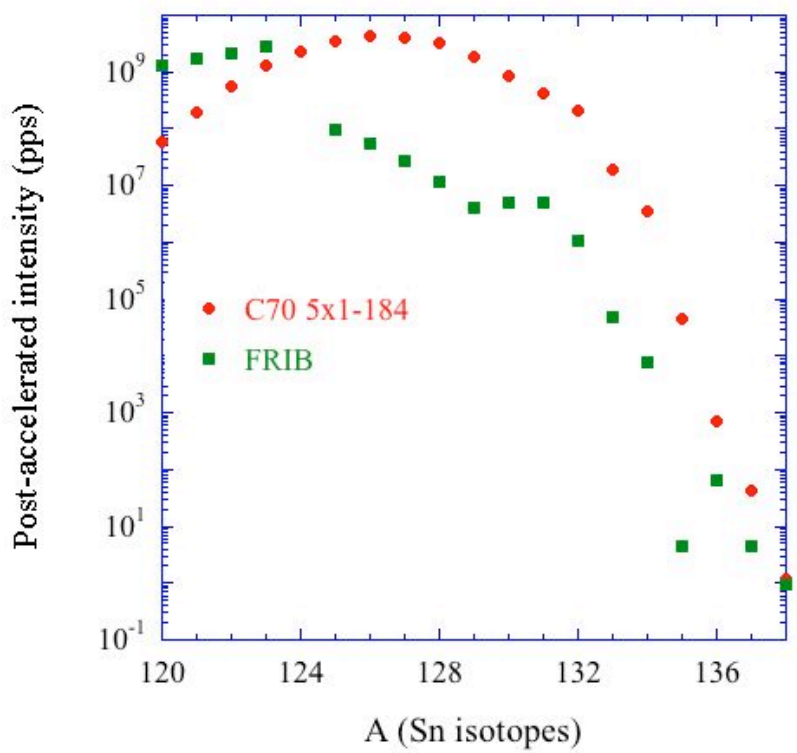
180 μA 70 MeV p
5 x 1.1 cm 6.6g/cm² UC



Neutron-rich beam yields

- **C70 U(p,f) baseline yields compared to FRIB**





Leadership Position with C70 Driver

- Excellent neutron-rich capability with scope to improve
- Some unique proton-rich beams
- Baseline ~15% of SPIRAL-2 yield for n-rich nuclei
- Comparable to ISAC-II for very neutron-rich nuclei
- Close to FRIB in key regions. Remember: FRIB will be a single-user facility!
- *Interesting applications, including isotope production R&D and stockpile stewardship*

	^{82}Ge	^{84}Ge	^{86}Ge	^{132}Sn	^{134}Sn	^{136}Sn
HRIBF (HDU baseline)	$3x10^6$	$8x10^4$	694	$2x10^8$	$2x10^6$	$1x10^3$

Baseline yields: ~40% of photofission driver
Up to 3x larger is possible

Leadership Position with C70 Driver

- Baseline: assumes large diameter target U(p,f) at ~180 μA, contribution from (n,f)
- Much higher RIB yield and improved reliability
- n-rich intensities up to ~40% of EDU
  - ~15% of SPIRAL-2,
  - ~30% to 50% of ISAC-II U(p,f) yield (oversimplified comparison).
- Established capabilities: Unique n-rich program with LeRIBSS, GRETINA, and selected p-rich beams (including ^{7,10}Be, ^{17,18}F, ^{26g}Al, ^{56}Ni…)
- Develop secondary neutron (n,f) capability
- *Parallel batch mode sample or isotope production*

	^{82}Ge	^{84}Ge	^{86}Ge	^{132}Sn	^{134}Sn	^{136}Sn
HRIBF (HDU)	3×10^6	8×10^4	694	2×10^8	2×10^6	1000
CARIBU	524	220	9	1×10^4	1400	5

mini SPIRAL-2

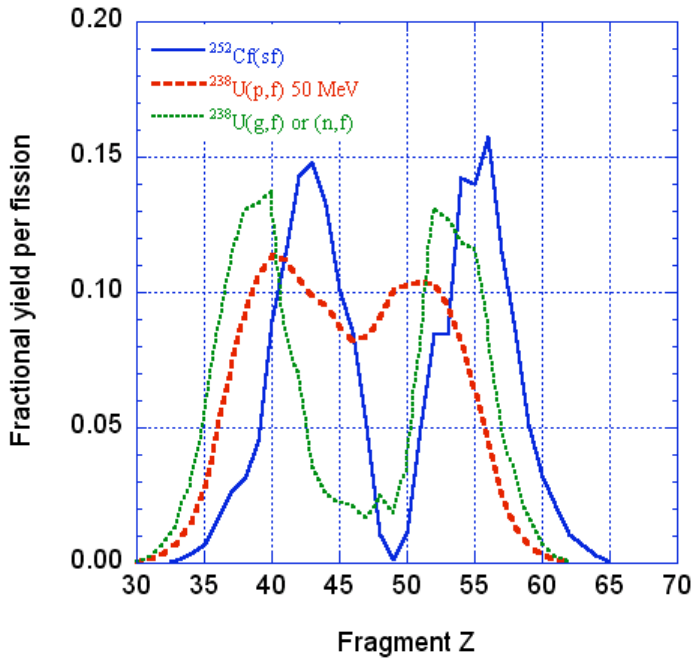
Summary of Project Benefits

- **Scientific Benefits**
  - Very large gains in neutron-rich RIB yield: extends unique research capability
  - Maintains and extends existing proton-rich capability
  - Produce long-lived isotopes for batch-mode beams locally
  - Can support an isotopes R&D program
- **Facility/Operational Benefits**
  - Fully replaces ORIC and expands on capabilities
  - Commercial accelerator sold for isotope production
  - Batch mode sample or isotope production while producing on-line RIB
  - *Much improved reliability* (effect on both n- and p-rich)
  - Much reduced power cost (~15% of ORIC)
  - All of the proposed equipment required for RIB production can be accommodated within the existing HRIBF facility,– no major civil construction
  - Existing RIB production systems, IRIS1 and IRIS2, can accept beams from the new driver.
  - No modifications are required to the existing 25 MV tandem post accelerator.
  - An isotope production vault and facilities can be constructed adjacent to the C70 vault.

Leadership Position with ORIC-based program

- Improved reliability
- 2-step (n,f) yields may exceed (p,f) yields by >15x at large n-excess
- Established capabilities.
  - Unique n-rich program with LeRIBSS, GRETINA
  - Selected p-rich beams (including ^{7,10}Be, ^{17,18}F, ^{26g}Al, ^{56}Ni…)

	^{132}Sn	^{134}Sn	^{82}Ge
HRIBF (p,f)	9×10^5	3×10^3	3×10^4
CARIBU	1.4×10^4	1.4×10^3	524



For ^{134}Sn intensity <2000 wrt ISAC-II
<5000 wrt SPIRAL-2

End of Talk