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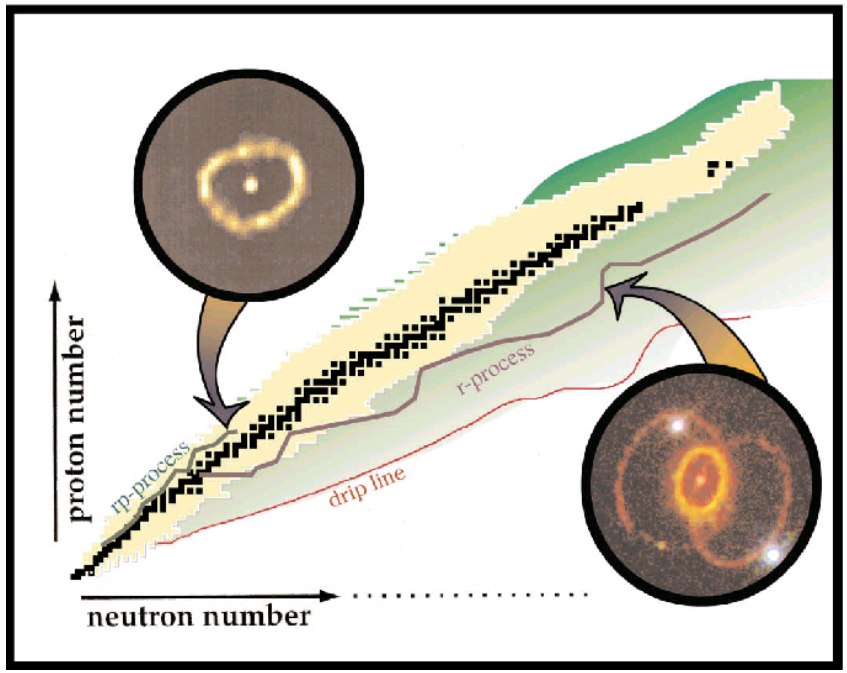
... for a brighter future

Advanced Exotic Beam Laboratory

Status



Accelerator Institute Quarterly Meeting
17 January 2007

U.S. Department of Energy

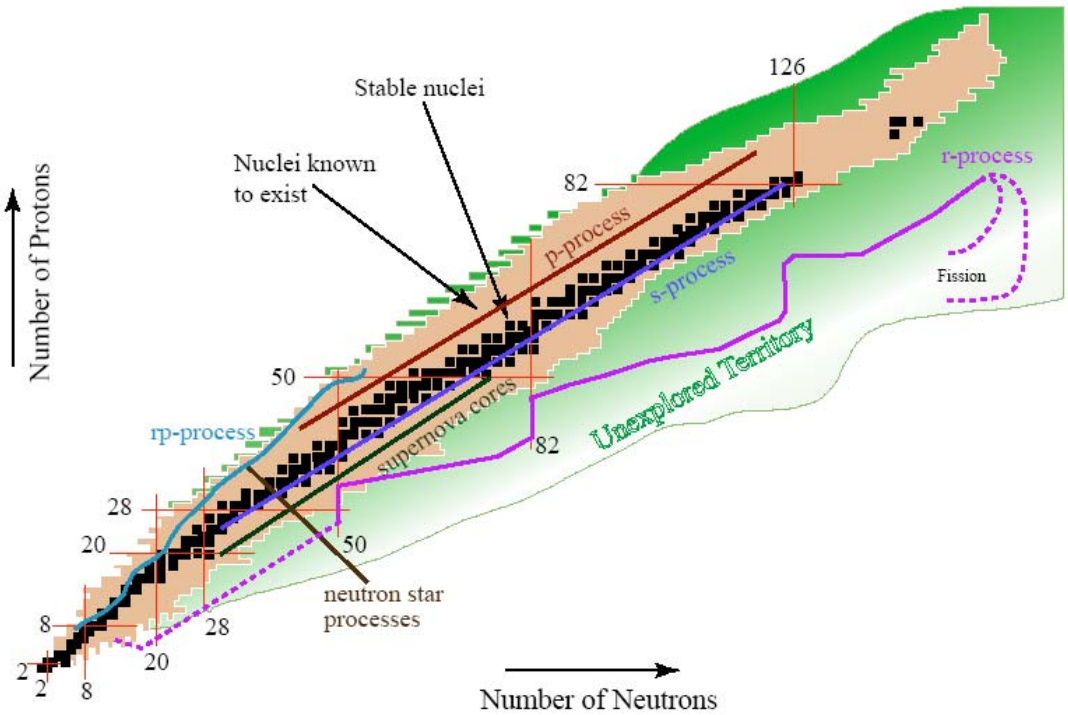
THE UNIVERSITY OF CHICAGO

Office of Science
U.S. DEPARTMENT OF ENERGY

A U.S. Department of Energy laboratory managed by The University of Chicago

The Need for Exotic Isotopes

- Continued advances in nuclear experiment, nuclear theory and in astrophysics reinforce the science case for exotic beams.
  - advanced simulations.
  - new experimental techniques, including ion and atom traps.
  - new observations
- We know nuclei far from the valley of stability are different than their more familiar, stable cousins, but there are serious competing ideas of why this is so.
- These exotic isotopes are key to exploring the grand scale behavior of the cosmos, including the origin of the heavy elements and the nature of stellar explosions.
- The bounty of isotopes produced by an advanced facility holds great potential for applications in science and technology.
- Manpower trained in the techniques of exotic isotopes are critical for our nation's workforce.



Present Context for Reinvigoration of Exotic Beam Thrust

- 2006 actions by DOE:

  Support R&D to start construction of a U.S. exotic beam facility for about half the cost of RIA with unique capabilities at the end of this 5-year period.

  – In DOE-speak this means a decision to go ahead in at the end of FY07 and a RFP for siting in 2008.

- The Science of RIA was evaluated by a US National Academy committee:

  RIA Scientific Assessment Committee —RISAC.

- NSAC Subcommittee charged to evaluate the scientific reach and technical options for a world class facility in the United States and to provide the guidelines for such a facility in a request for proposals. NSAC is asked to submit a final report with their guidelines at the end of March 2007 in preparation for the formulation of the 2007 NSAC Long Range Plan. The Long Range Plan writing group will meet a month later to prioritize its recommendations for the future,

Conclusions of RISAC report

- Nuclear structure and nuclear astrophysics constitute **a vital component of the nuclear science portfolio** in the United States.
- **Failure to pursue** a U.S.-FRIB would likely lead to a **forfeiture of U.S. leadership** in nuclear-structure-related physics and would **curtail the training of future U.S. nuclear scientists.**
- A U.S. facility for rare-isotope beams of the kind described to the committee would be **complementary to existing and planned international efforts**, particularly if based on a heavy-ion linear accelerator. With such a facility, the United States would be a **partner among equals** in the exploration of the world-leading scientific thrusts listed above.
- The science addressed by a rare-isotope facility, most likely based on a heavy-ion driver using a linear accelerator, should be a **high priority** for the United States. The facility for rare-isotope beams envisaged for the United States would provide capabilities **unmatched elsewhere** that would help to provide answers to the key science topics outlined above.

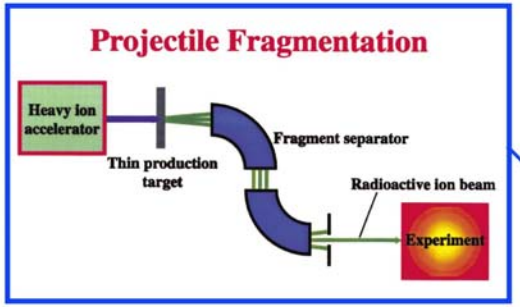
How to Develop a Concept at Half the Price

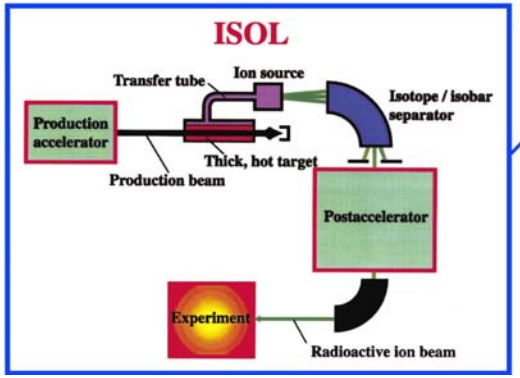
- **Achieve the rare isotope physics goals in a global context**

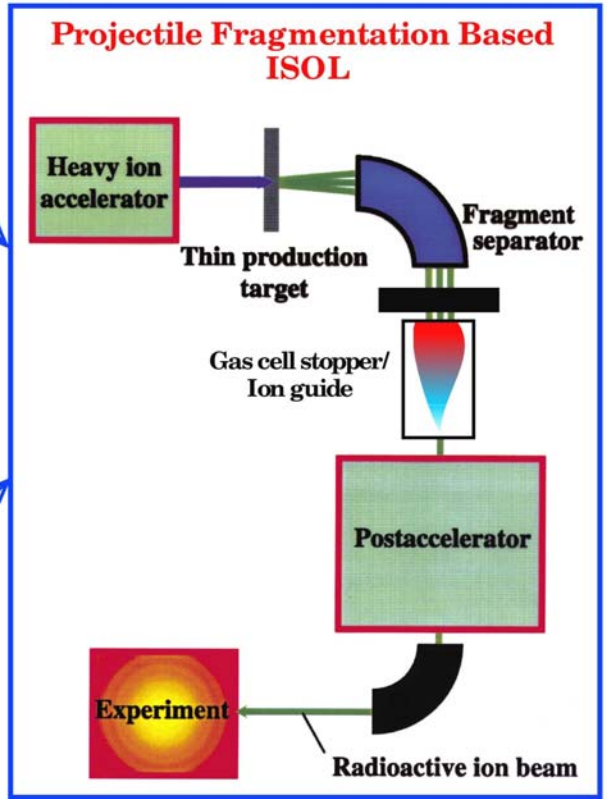
- **Proposed approach: a US program that focuses on uniqueness and recognizes complementarity**
  - **Identify key experiments**
  - **See what part the present or under construction international facilities can address**
  - **Identify the beam/facility requirements that a new facility to complement the existing international arsenal must have**
  - **Design a facility that meets these requirements within the budget envelope**

There is the only one facility on the horizon that combines all these features: Rare Isotope Accelerator/Advanced Exotic Beam Laboratory

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

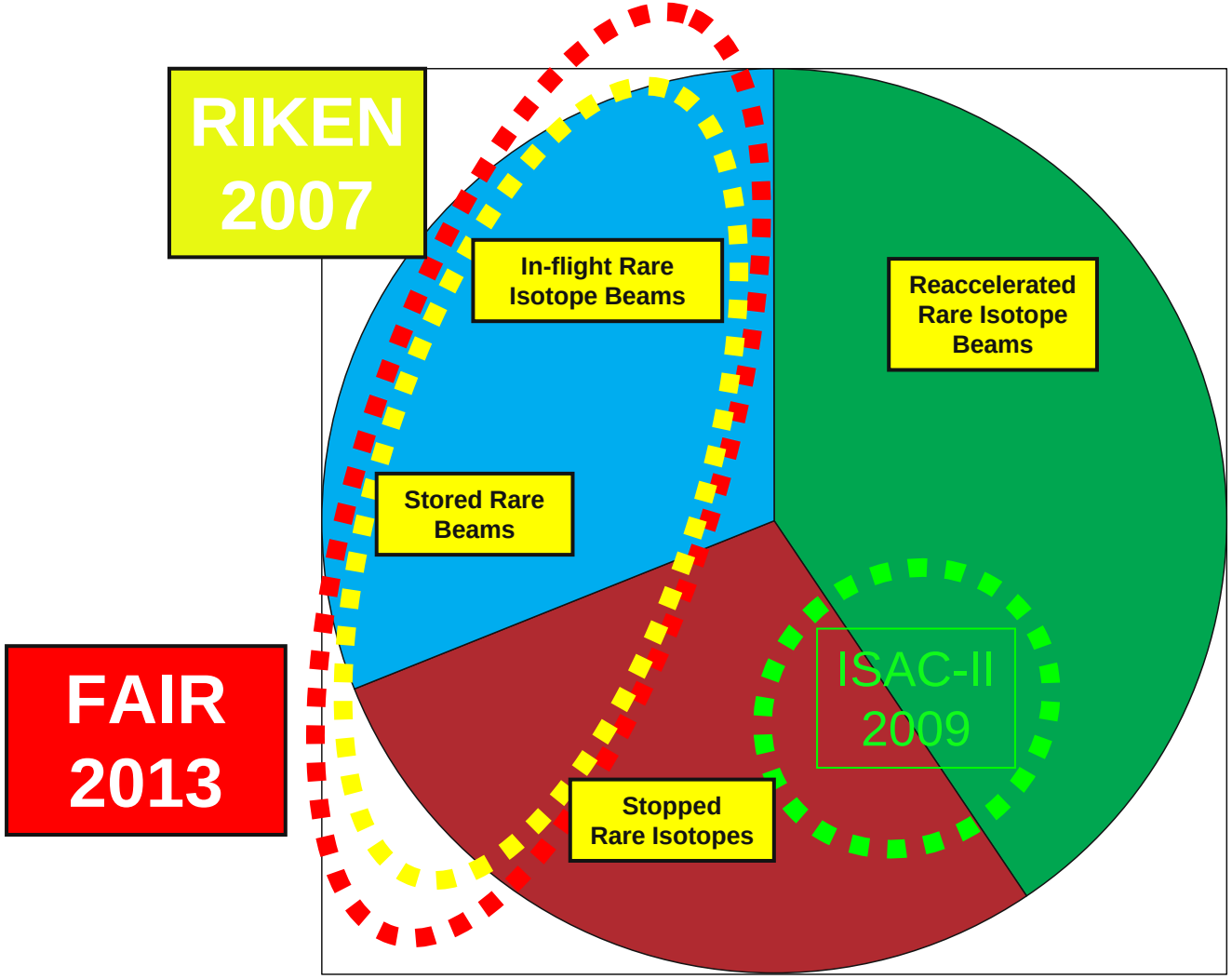




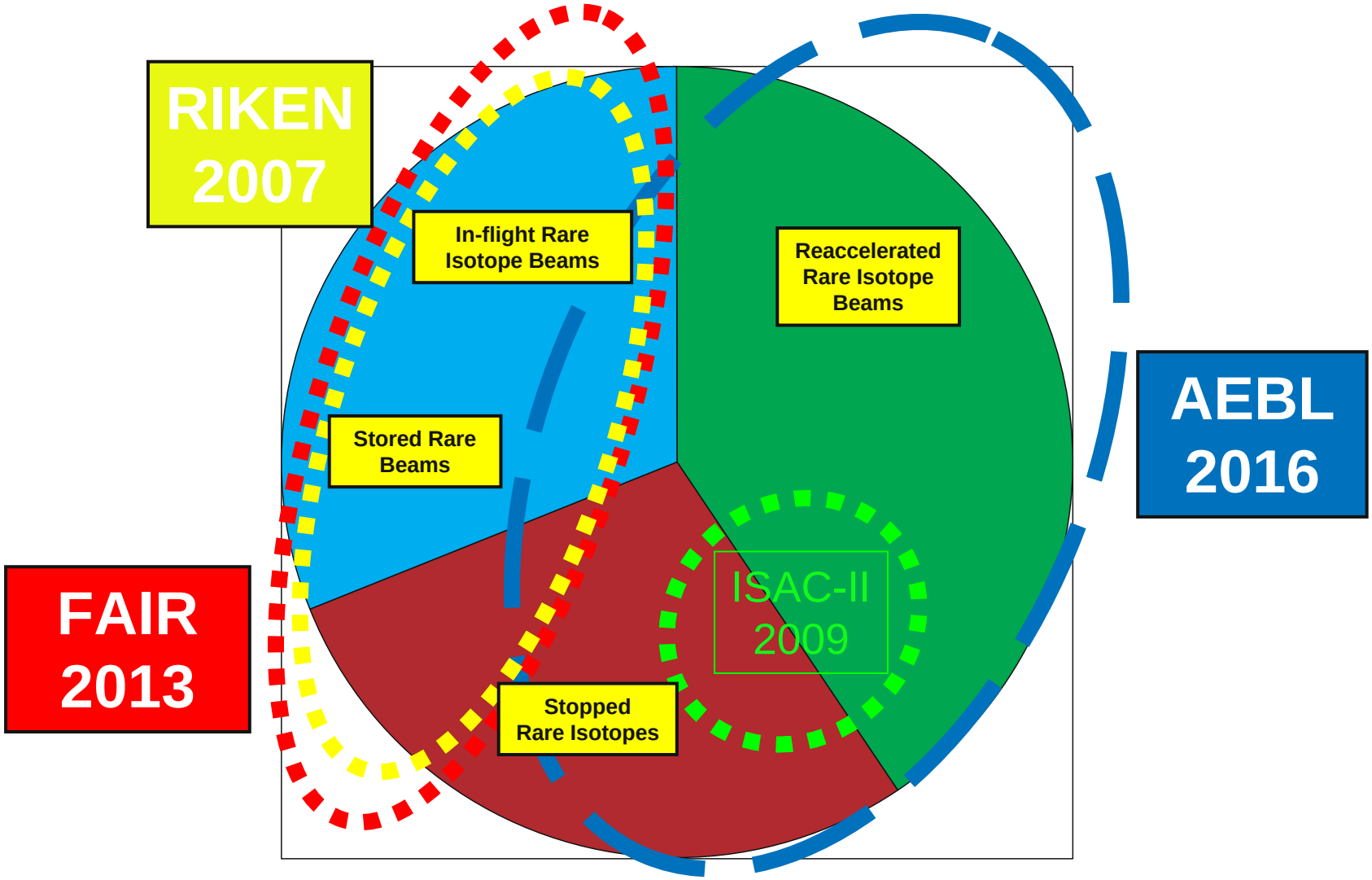


- Fast Gas Catcher to combine advantages of fragmentation and stopped beams
- Superconducting driver linac and post-accelerator for all ions from hydrogen to uranium.
- Acceleration of ions in multiple charge states to increase performance.
- Realizable designs for high power (>100 kW) targets.
- Efficient reacceleration of 1+ charge states.

How the suite of international facilities address the full program of rare isotope science



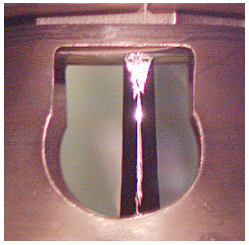
How the suite of international facilities address the full program of rare isotope science



Key concepts demonstrated to make the gas catcher approach ready for prime time …. important role played by RIA R&D

- **400 kW heavy ion driver**
  - ✓VENUS ECR source development (LBNL)
  - ✓Multiple charge state acceleration development (ANL)
  - ✓Cavity prototyping (ANL, JLAB, MSU)

- **400 kW fragmentation target**
  - ✓Liquid lithium target development and test (ANL)

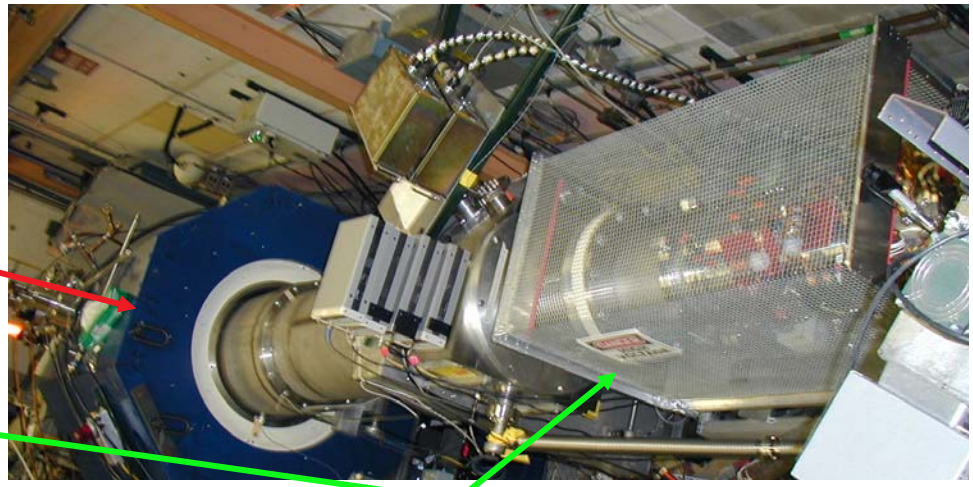


- **Fragment separator**
  - ✓High acceptance fragment separator development (ANL, GSI, MSU, RIKEN)

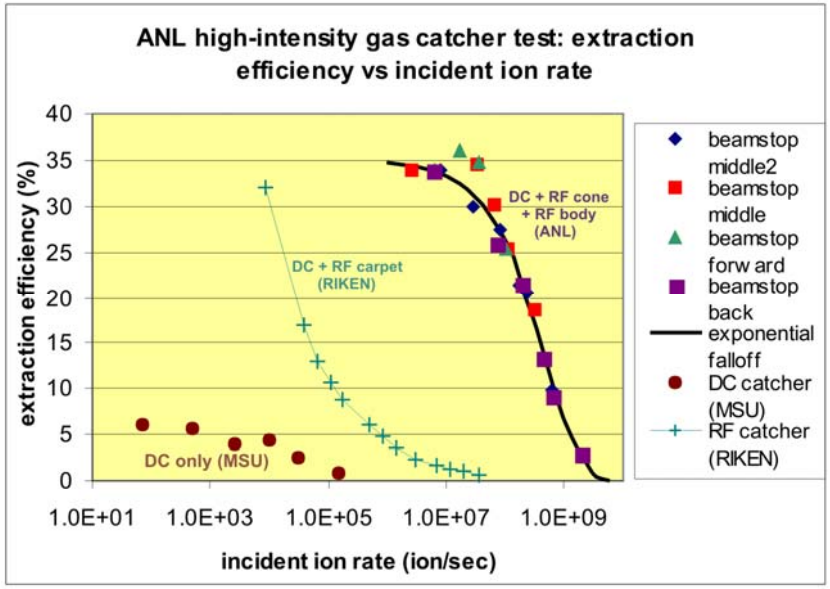
- **Gas catcher**
  - ✓Gas catcher development and demonstration at low energy (ANL)
  - ✓Demonstration of gas catcher operation at RIA energy (ANL, GSI, …)
  - ✓Demonstration of gas catcher operation at RIA intensity (ANL)

Gas catcher operation at RIA/AEBL/CARIBU intensity

- **High intensity beamline built at ANL to reproduce ion distribution expected behind RIA/AEBL fragment separator**
  - **Focusing by 68 cm bore superconducting solenoid**
- **Large gas catcher using large RF cone developed for high energy test at GSI, combined to full body RF focusing**



- **First tests at high intensity beamline in Sept and Oct 06**
  - **High efficiency obtained at up to 10^9 incoming particles per second**

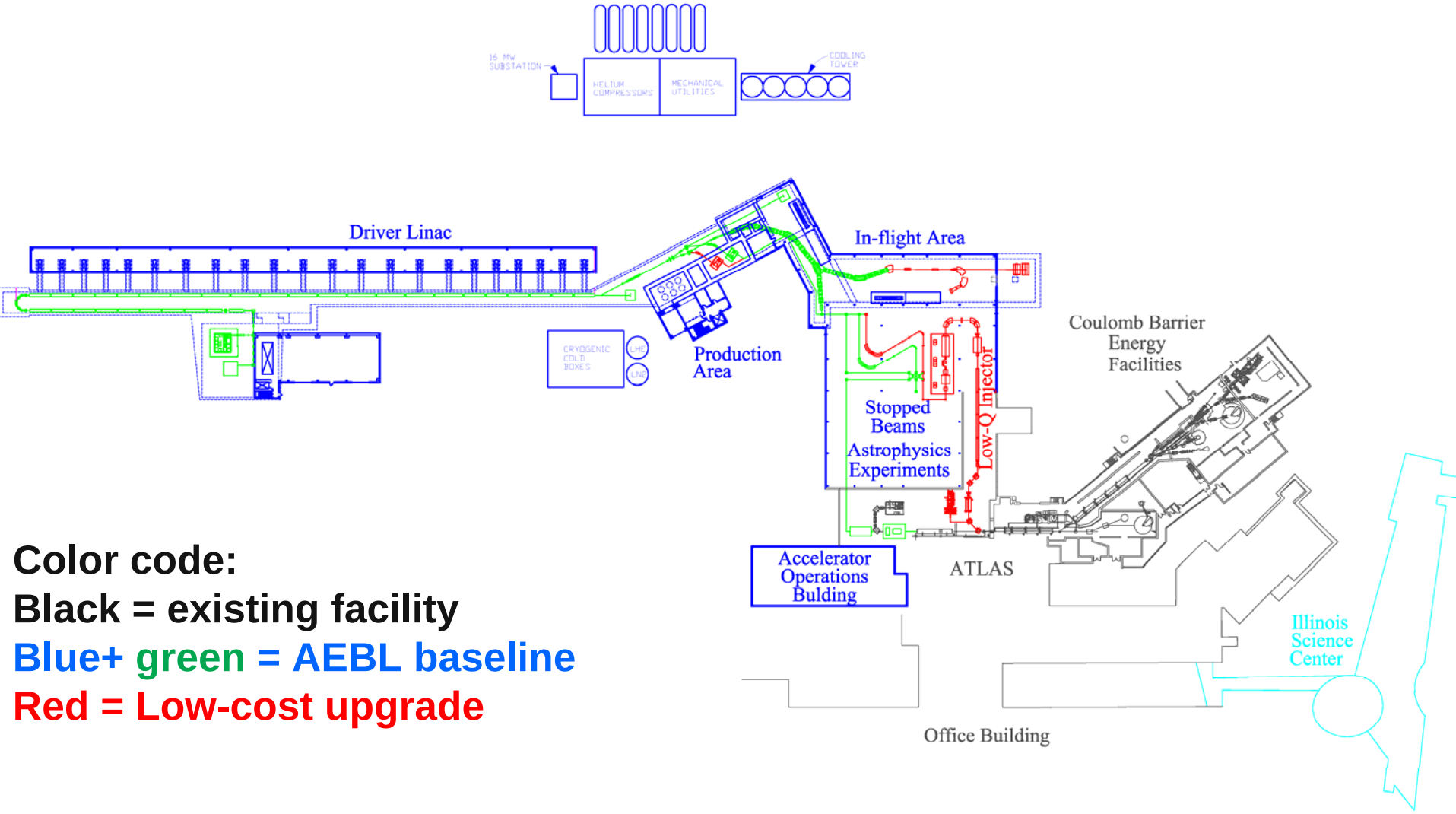


The Advanced Exotic Beam Laboratory: AEBL

AEBL is a superconducting linac

- **Accelerates several charge states simultaneously**, producing 580 MeV protons to 200 MeV/u uranium - 400 kW.
- **Focus on reaccelerated beams**
  - *1 in-flight target and separator for gas catcher*
  - *1-2 ISOL targets*
- **Same beam power as RIA**
  - *Small in-flight area for identification and collection of implanted ions, i.e. half-lives for r-process.*
  - *For most isotopes, reaccelerated beam intensities comparable to RIA.*
  - *In worst cases, intensities still 10-20% of RIA.*
- **Roughly 1/2 the cost of RIA**
  - *Sharply decreased costs, with only moderately weakened capabilities, result from*
    - Reduced energy of linac, removed large fragmentation experimental area, other conventional facility savings
    - Progress from exotic beam R&D
    - Reuse of existing ATLAS experimental equipment (CPT/APT, FMA, Gammasphere, laser traps) and new experimental equipment now under construction (HELIOS, Gretina, GRETA)
  - *Cost estimates include contingency*

Layout of AEBL at ANL – 200 MeV/u, 400 kW



Color code:

Black = existing facility

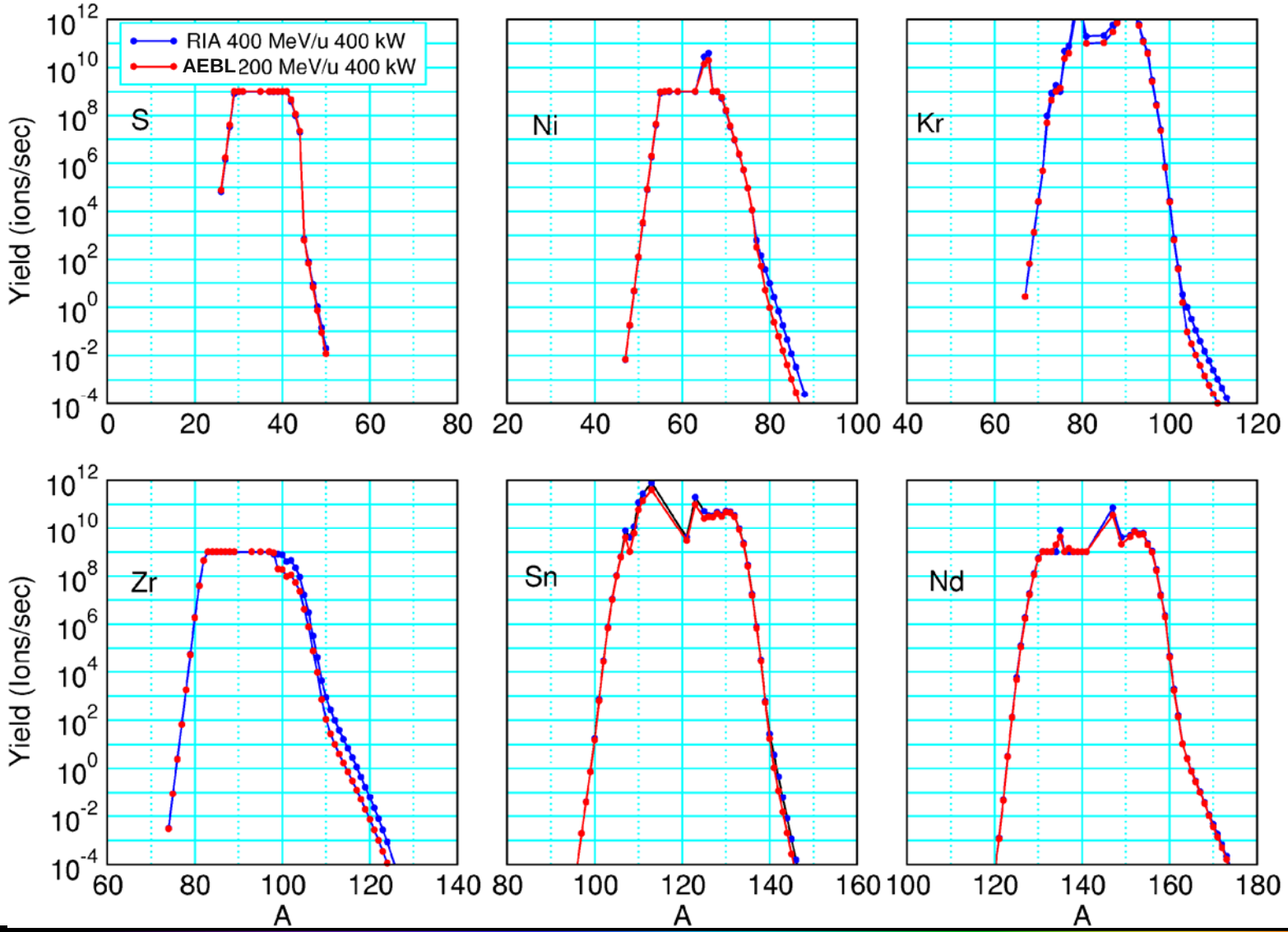
Blue+ green = AEBL baseline

Red = Low-cost upgrade

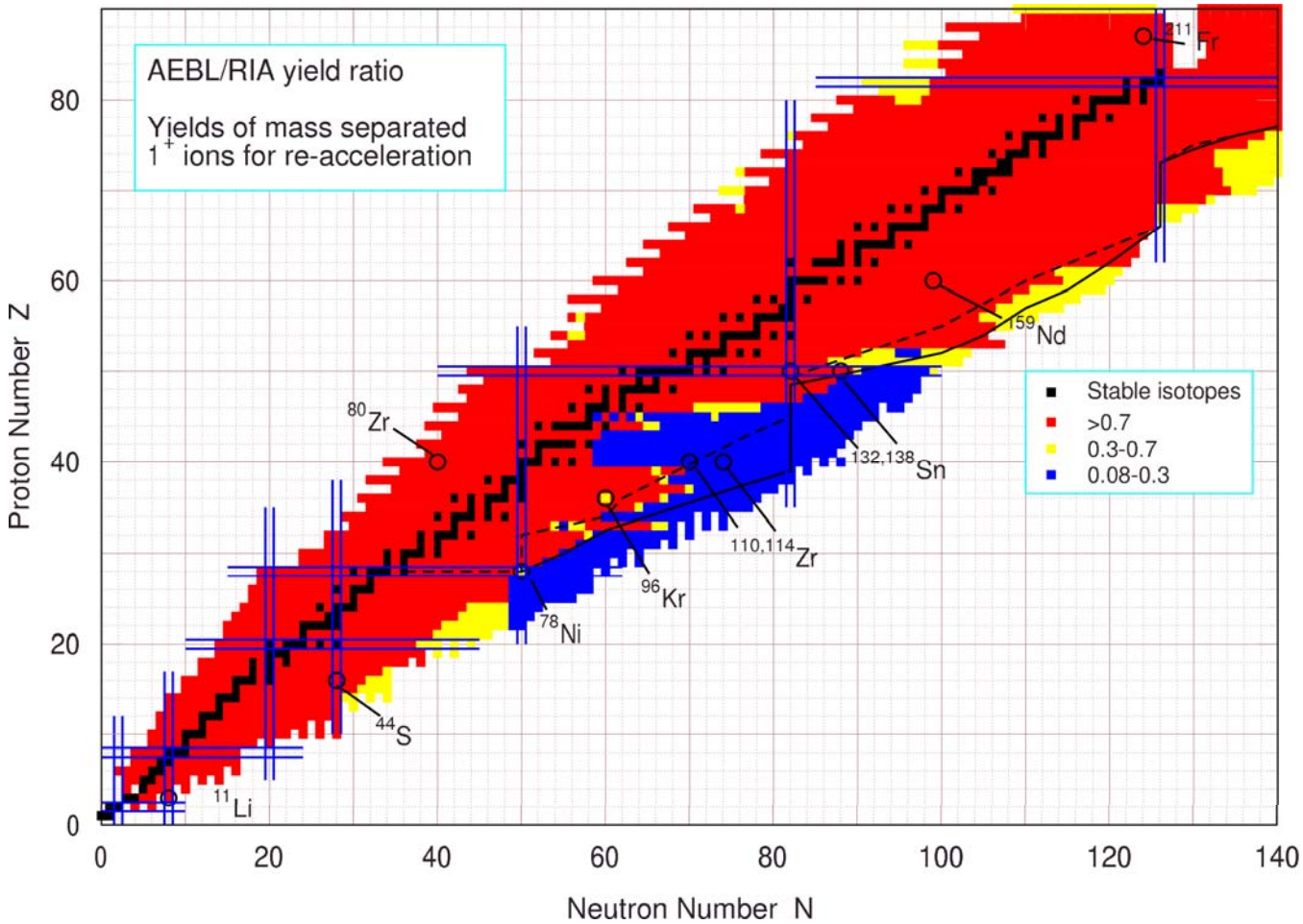
Major systems

- Driver linac
  - 2 ECR ion sources (high-intensity ECR + existing ECR), CW RFQ
  - 207 SRF cavities, 31 cryostats, 85 SC solenoids
  - One liquid lithium stripper (17 MeV/u) and magnetic chicane
- One ISOL target, available space for an additional target
- Fragmentation targets, fragment separator and Gas cell
- In-flight radioactive beams delivered to the experimental area (~7000 sq.ft)
- 1:20000 Isobar separator, charge breeder, CW RFQ
- Large stopped-beam/low-energy experimental area (23700 sq.ft)
  - Will house low-q RIB linac as an upgrade option
- Existing ATLAS facility
- Existing instrumentation
- Illinois Science building (office space for 162 people, provided by Illinois State
- Facility requires
  - 11 acre area
  - 2.4 kW 2.1ºK cryoplant with distribution system (40% margin)
  - 18 MW electrical power (including ATLAS)
  - Utilities (water cooling, A/E)

RIA vs AEBL comparison for 1⁺ ions for traps and reacceleration

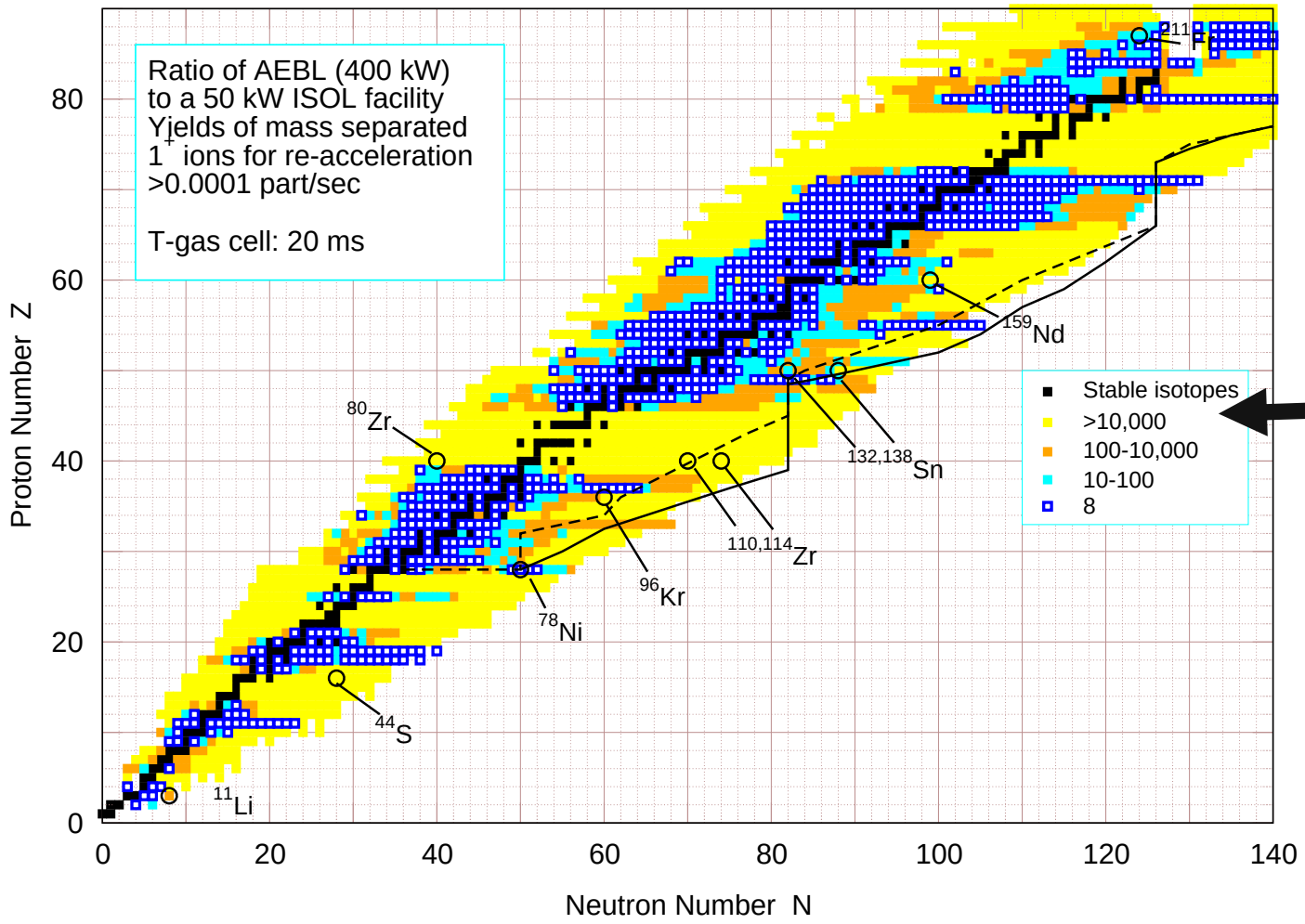


Yield of AEBL facility vs full RIA



In most cases the intensity is the same within 20%.
The ratio is never worse than a factor of 12.

A comparison to the best, currently-projected reaccelerated beam facility: Beam intensity ratio: AEBL vs 100 kW ISOL facility



Over half the nuclides needed for the science are not available from ISOL sources.

What you keep, what you give up

- **Keep**
  - **Essentially same yield for all species in 3 experimental areas**
    - **Stopped beams**
    - **Astrophysics energy**
    - **Coulomb barrier energy**
  - **Experimental areas and most equipment for**
    - **Stopped beams**
    - **Astrophysics energy**
    - **Coulomb barrier energy**
  - **Similar yield for fast beams but lower energy and limited fast beam Experimental area**
- **Give up**
  - **Some multi-user capabilities**
  - **Highest energy for fast beams**
    - **Reduced purity in small fast beam area for heaviest elements**
  - **Most fast beam equipment**

But this is what the rest of the world will do best!

AEBL WBS elements re-grouped for high-level comparison

Advanced Exotic Beam Laboratory - AEBL Conceptual Cost Estimate in FY2006 ($M)																
Escalated 2001 Harrison Committee numbers are **blue** and AEBL numers are **red**																
WBS Category (Harrison)	Management		Cryogenic Plant		Driver Linac		Exp. Safety		Target Systems		Low Energy		High Energy		Total ($M)	
	Harrison (06)	AEBL	Harrison (06)	AEBL	Harrison (06)	AEBL	Harrison (06)	AEBL	Harrison (06)	AEBL	Harrison (06)	AEBL	Harrison (06)	AEBL	Harrison (06)	AEBL
Central Facilities (1.1)	50	30	52	24											102	54
Civil and Utilities (1.2)	32	55	5	7	30	20			21	10	29	15	24	9	142	116
Driver Linac (1.3)					239	140									239	140
Experimental Facilities (1.4)							11	10	51	20	139	41	94	0	295	71
Total Estimated Cost TEC	81	85	57	31	269	159	11	10	72	31	168	56	118	9	777	381
Other Project Costs OPC															213	47
Total Project Costs TPC	81	85	57	31	269	159	11	10	72	31	168	56	118	9	990	427

- Generally the AEBL numbers are less than half of the RIA numbers due to reduced scope, much smaller conventional building areas and corresponding reduced floor space and no new research instruments.
- The driver linac is more cost effective because R&D has led to higher gradients, less cryogenic load and fewer cavities.
- The central utilities and management estimate for AEBL is higher than before because a sizable title III oversight and construction management cost has been added to this WBS element.
- The pre-ops component of OPC is reduced significantly from the relatively comfortable number in 2001.

Cost vs Capability

- These costs are our best estimate (based on seven years of RIA and SNS design experience) until a full conceptual design report is funded.
- Based upon these estimates, a facility with the critical capabilities can be built for ~$550M as-spent dollars.
- To stay within this cost cap, difficult decisions were made
  - reduced multi-user capability
  - reduced astrophysics area reacceleration intensities from charge breeder
  - smaller experimental areas
  - limited suite of new experimental equipment
- On the bubble – ISOL (in addition to gas catcher) vs in-flight equipment
  - ISOL takes advantage of planned reaccelerated and stopped equipment
  - provides highest intensities for super-heavy production and fundamental interaction studies
  - straightforward multi-user capability.

What is the scope of proposed R&D program? B: Remaining high priority items

- Note: there are no technical show-stoppers but a vigorous R&D program can substantially reduce cost and schedule risk of the project.
- Based on progress in the past 2 years of RIA R&D several high priority items remaining to be developed prior to PED (these are items indicated on the annotated version of the May, 2004 update):
  - SRF: fast tuners/phase control, high power coupler evaluation, cryomodule performance and alignment methods
  - Complete the 2-q driver injector and RFQ prototype demonstrations
  - Develop and test 9T SC solenoids with integrated steering coils.
  - Complete studies of linac tunes over a broad range of primary beams; develop compact/clean diagnostics box with psec timing capability for tuning multi-q beams; integrate beam dynamics simulations with modeled diagnostics information.
  - Complete liquid lithium stripper development including in-beam tests at full power density – using SARAF linac in Israel most likely
  - Develop concepts for cost-effective, rad-hard large aperture rectangular superconducting multipoles for the fragment separator; continue development of the liquid tin beam bump for the fragment separator
  - Continue improvements in gas cell technology to increase intensity limits and to increase collection efficiency for light radioactive isotopes

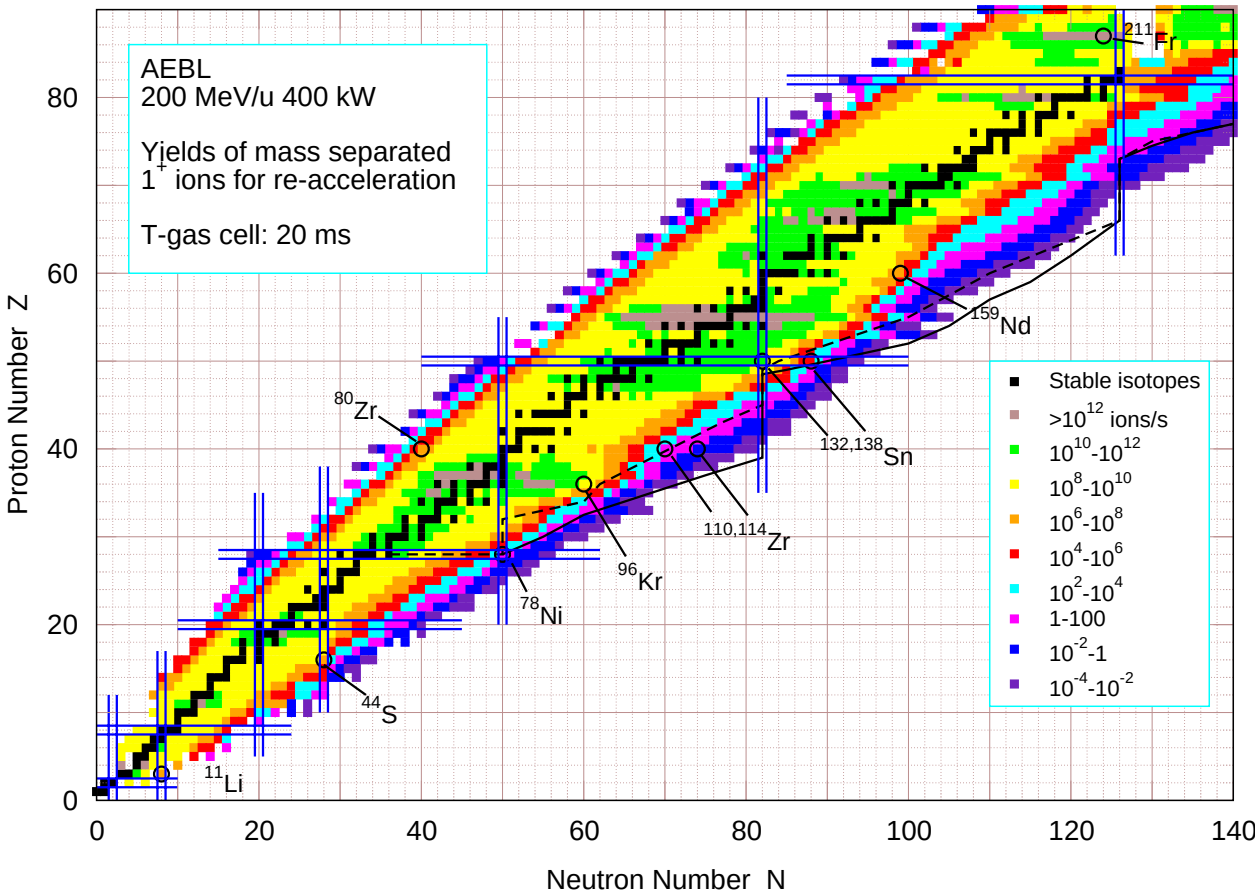
Argonne has chosen a path forward for an advanced exotic beam facility that

- Complements the major investments in Europe and Japan in fast-beam fragmentation facilities by focusing on unique reaccelerated exotic beams.
- Vastly exceeds the capabilities of all reaccelerated beam facilities.
- Provides the higher reaccelerated beam energies needed to do transfer reactions well (single particle structure and pairing).
- Can be built for about ½ the cost of RIA by capitalizing on existing Argonne strengths and facilities.
- We anticipate an RFP next year.
- Subject to continuing resolution, expect exotic beam R&D to continue near current levels.
- MSU has a similar 200 MeV/u design, but focusing more on in-flight beams.

New technology leads to vastly improved isotope yields

The orders-of-magnitude improvements in AEBL's rare isotope yields compared to other facilities are due to:

- Superconducting driver with multiple charge state acceleration.
- New production target technologies, especially the fast gas catcher.
- Most efficient rare isotope reacceleration scheme, starting with 1+ charge states.



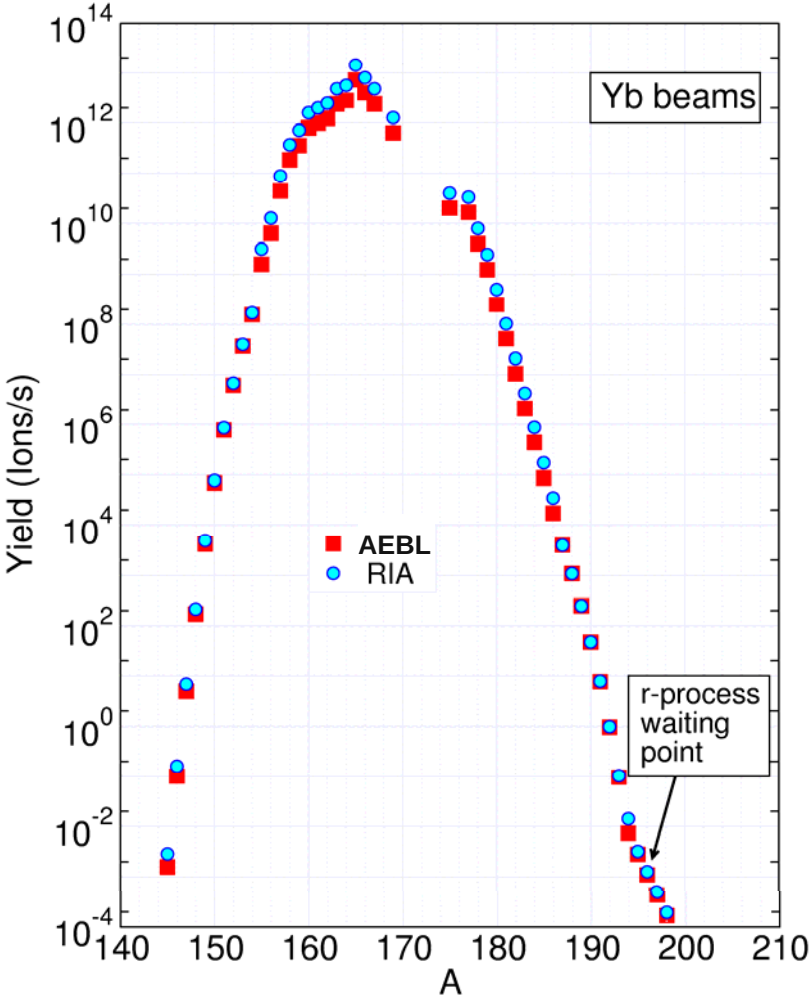
Capabilities needed to answer the 12 science examples

	AEBL		*low energy facility limitations without AEBL*	RIKEN AND FAIR
Science Examples	Reaccelerated	Stopped		In-Flight/Stored
1. Shell Structure	**Yes**		a, b	**Yes**
2. Super-heavies	**Yes**		c	
3. Neutron skins	**Yes**	**Yes**	b	**Yes**
4. Pairing	**Yes**		a, b	
5. Dynamical Symmetries	**Yes**		b	
6. Nuclear Eq. of State				**Yes**
7. r-process		**Yes**	b	**Yes**
8. Direct astro reactions	**Yes**		b	
9. s-process		**Yes**	b	
10. Applications		**Yes**	b,d	
11. Stockpile Stewardship	**Yes**	**Yes**	b,d	
12. Fund. Symmetries		**Yes**	a, b	

a) energy limitations
b) species limitations
c) intensity insufficient
d) not in the US

What do we lose with AEBL compared to a full RIA?

- 1-2 neutrons in reach in half-life measurements for r-process nuclei, but will get to longest waiting points
- Neutron drip line except for light nuclei
- For a range of ~2-4 neutrons. in-flight ground state single particle breakup and Coulomb excitation to lowest 2+ states might be better done at RIKEN or GSI with a loss of ~1-2 neutrons compared to RIA
- Charge exchange reactions to measure electron-capture rates (at 10^7 ions/s)
- Equation of state of hot nuclei matter
- Limited simultaneous user capability



In all cases the yields are an extrapolation and subject to an order of magnitude uncertainty.

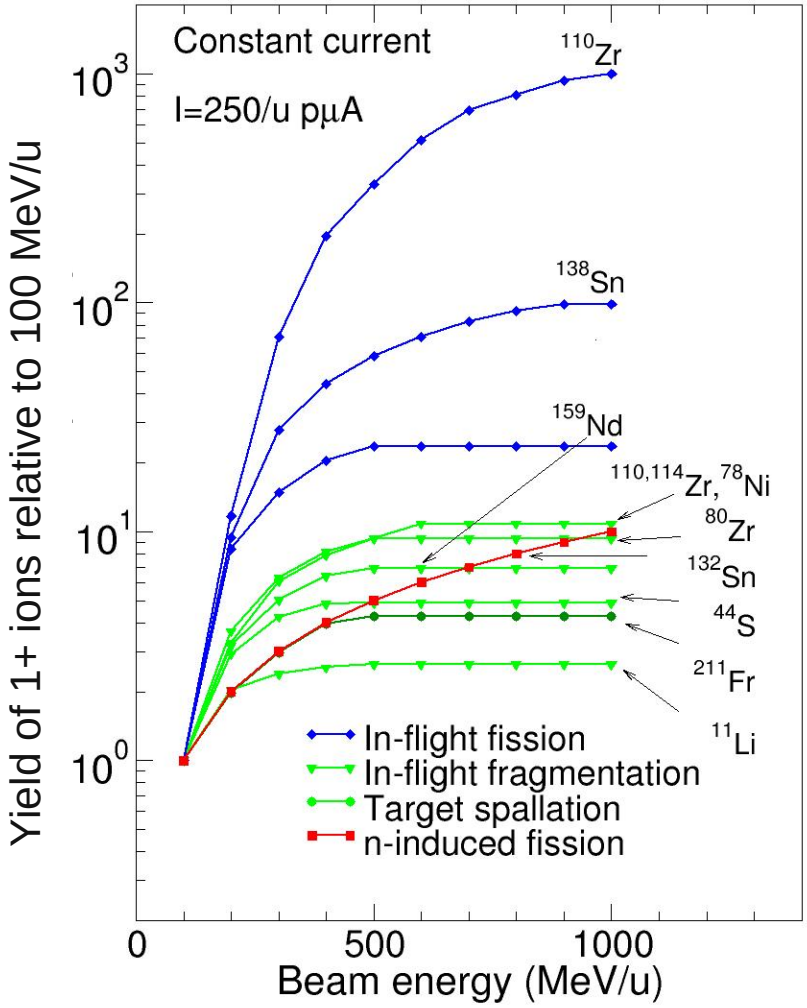
History and current situation

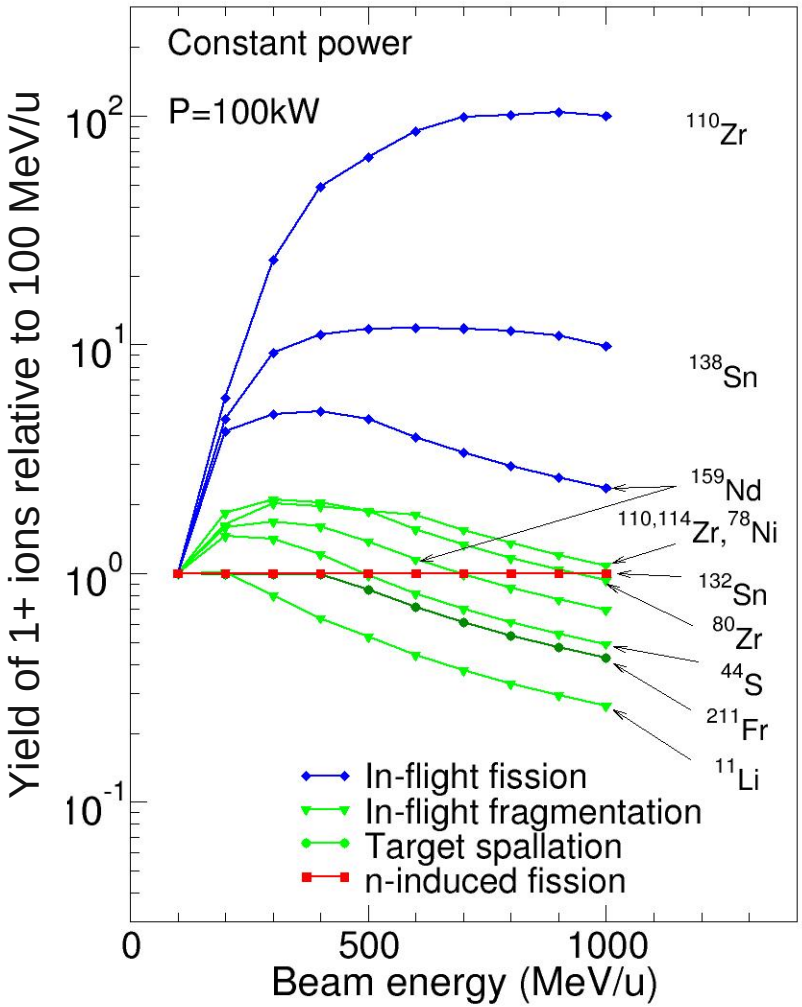
- 1996 NSAC Long Range Plan recommendation for in-flight facility (NSCL CCF) and a reaccelerated beam facility when RHIC construction is substantially complete.
- 1999 NSAC ISOL Task Force:
  - *RIA concept-The scientific potential of the RIA facility will be maximized by integrating multiple techniques for producing and separating then accelerating and utilizing these isotopes.*
  - *The RIA design should accommodate fast in-flight separated beams.*
- 2002 NSAC Long Range Plan:
  - *RIA is the highest priority for major new construction.*
- 2003 DOE 20-year Facilities Plan:
  - *RIA is tied for third.*
- Extensive RIA R&D efforts involving all major US laboratories have resolved the technical issues.
- Detailed facility plans developed at ANL and MSU, received wide support from the user community.
- Authorization legislation directing DOE to start RIA by 2008.
- 2004 Draft Request for Proposals – canceled when President's 2006 budget appeared.

If you need to stage RIA

- For reaccelerated beams, the issue is production rate, impacted by:
  - cross section vs energy,
  - separator acceptance vs energy,
  - charge state purity vs energy,
  - for many isotopes, beam power is more important than energy.
- No other facility proposes **reaccelerated** beams produced by fragmentation and in-flight fission of heavy ions followed by **gas stopping**.
- There are only limited plans at other facilities for any reaccelerated beams above 9 MeV/u (until EURISOL).
- For in-flight experiments, changing the primary beam energy leads to some physics issues – beam purity gets worse for heavy nuclei that are not fully stripped; optimum energy for some types of experiments.
- RIKEN (2008, 350 MeV/u) and GSI (2011, 2000 MeV/u) will have fast in-flight beams.

Energy dependence of rare isotope production



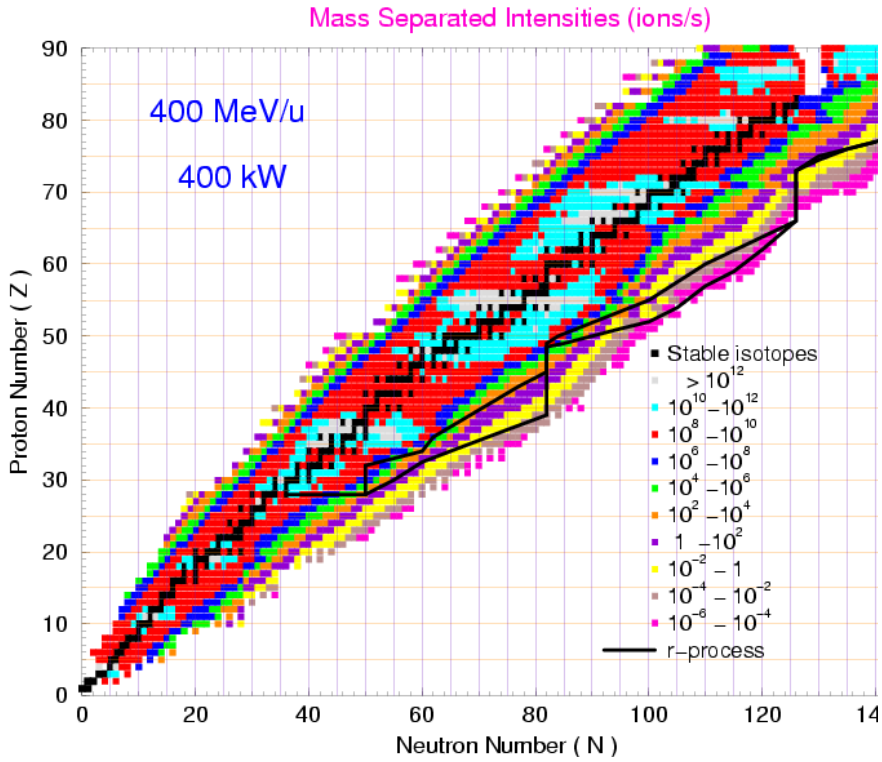


Beam energy (MeV/u)

RIA Isotope Yields

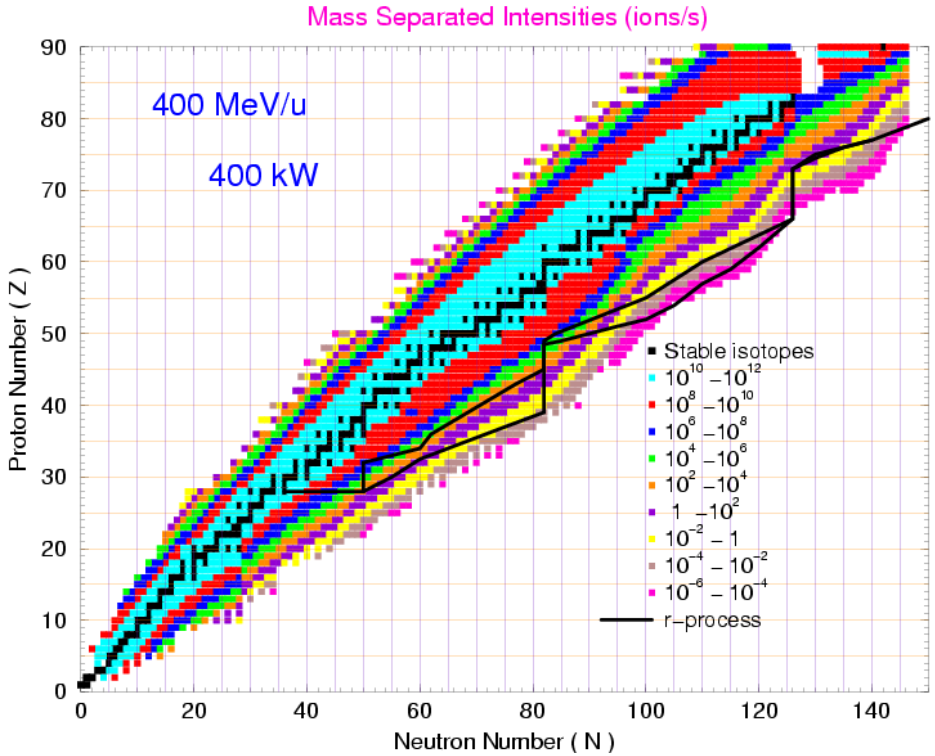
These are available as isotopically pure beams.

RIA Yields of 1^+ Ions for Reacceleration



These are typically available as fast, mixed beams.

RIA Yields of Fast Fragmentation Beams



See www.phy.anl.gov for predicted yield of every isotope