Nuclear Physics Experiments at the NSCL

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Discovering and Studying New Isotopes and
Exploring the Origin of the Elements in the Universe

Atomic Nuclei are Made of Protons and Neutrons

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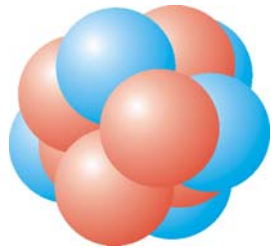
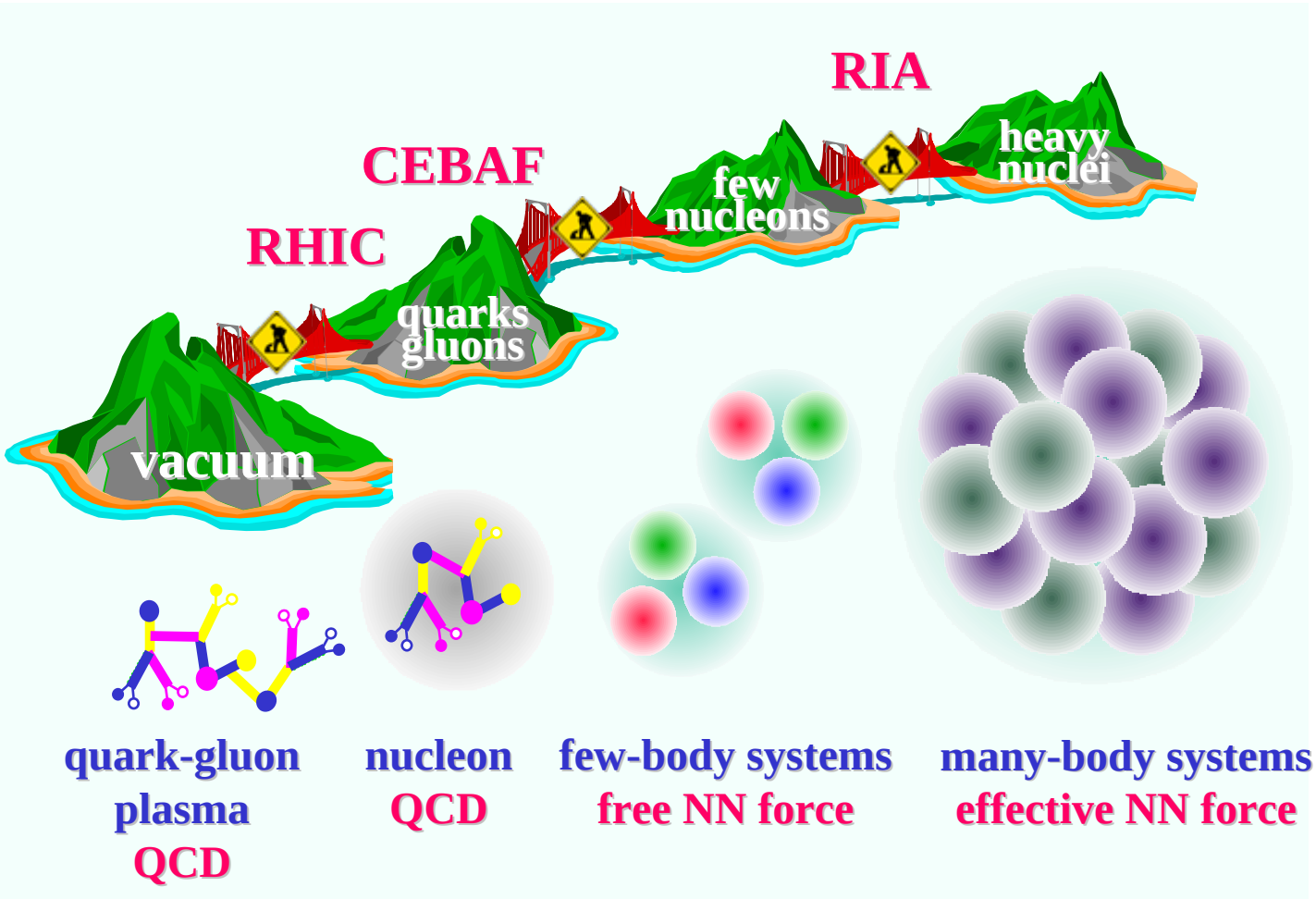
- The number of protons, Z, determines the chemical element.
- The atomic weight is given by A = Z + N, where N is the number of neutrons.
- Fewer than 300 isotopes are stable, all others are unstable ("radioactive").



- Short-lived isotopes cannot be found on earth -- they have long decayed since earth was formed
- Some radioactive isotopes provide major medical benefits through diagnosis or treatment of diseases; others have important applications, e.g., in biological sciences, environmental sciences, archeology, national security and energy generation.
- We are now able to produce thousands of rare isotopes in the laboratory and explore their properties.

From Simplicity to Complexity



Thomas Jefferson National Accelerator Facility

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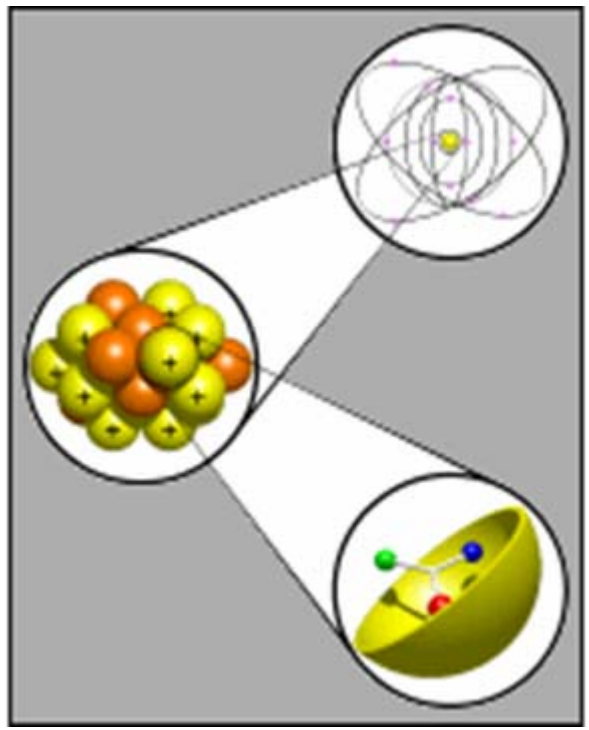
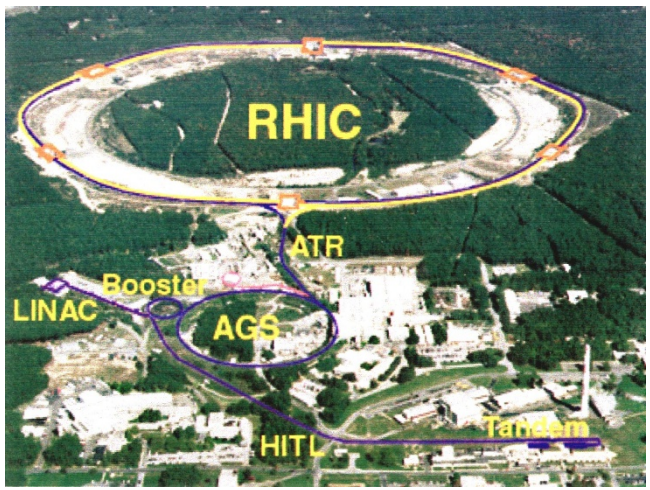
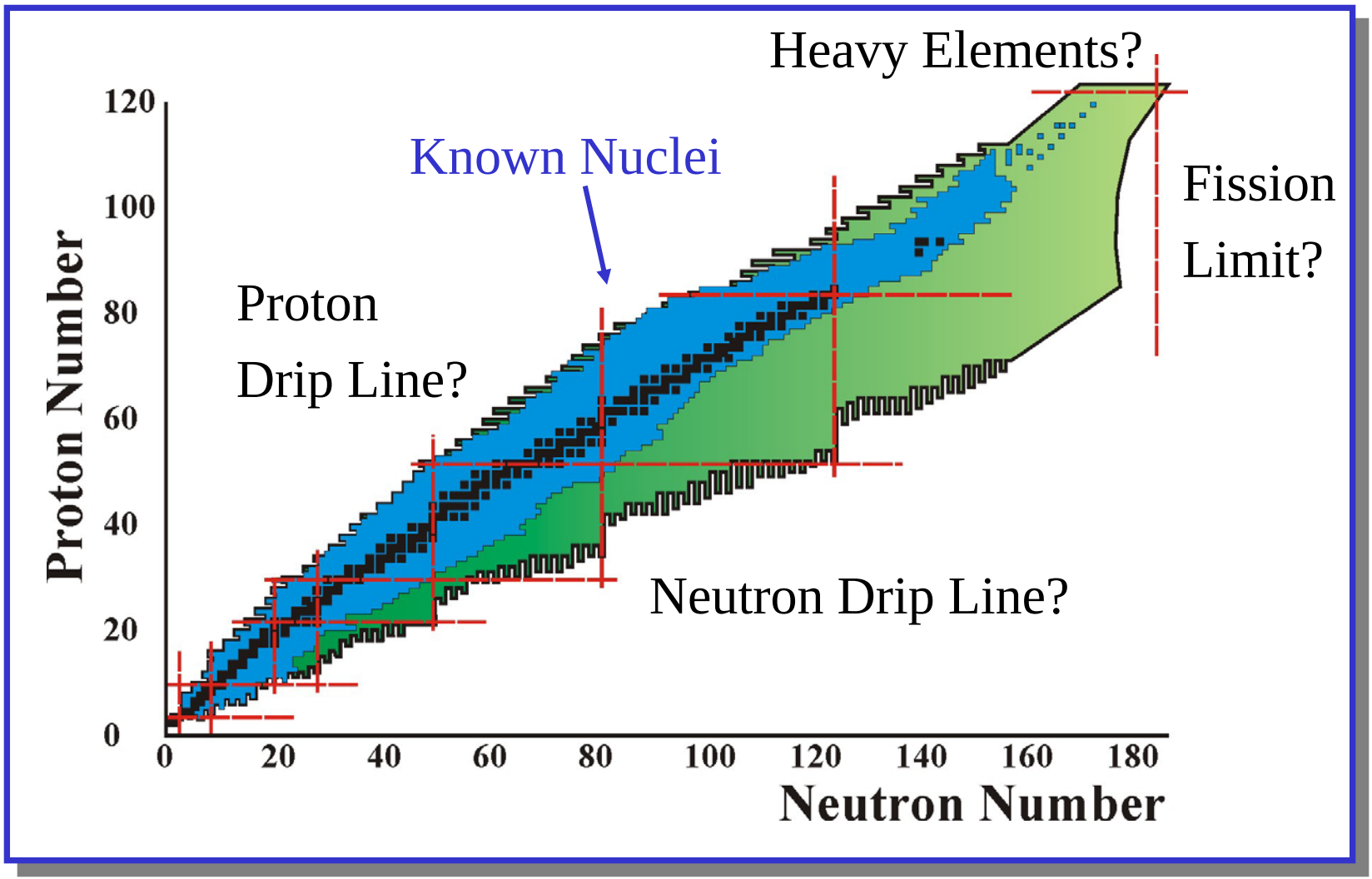
TJNAF or Jefferson Lab or JLab or CEBAF = Continous Electron Beam Accelerator Facility



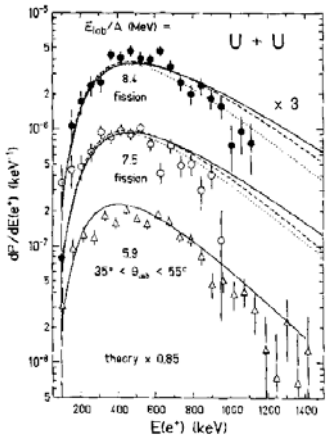
The Relativistic Heavy Ion Collider



The Chart of the Nuclides

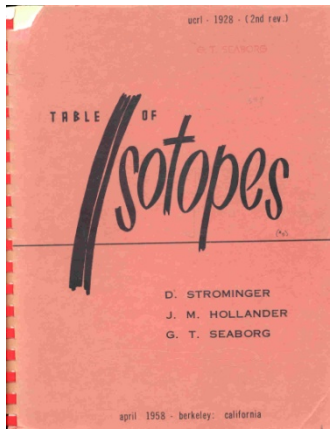


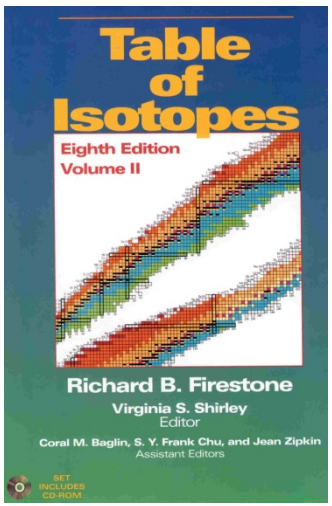
Nuclear “Structure”

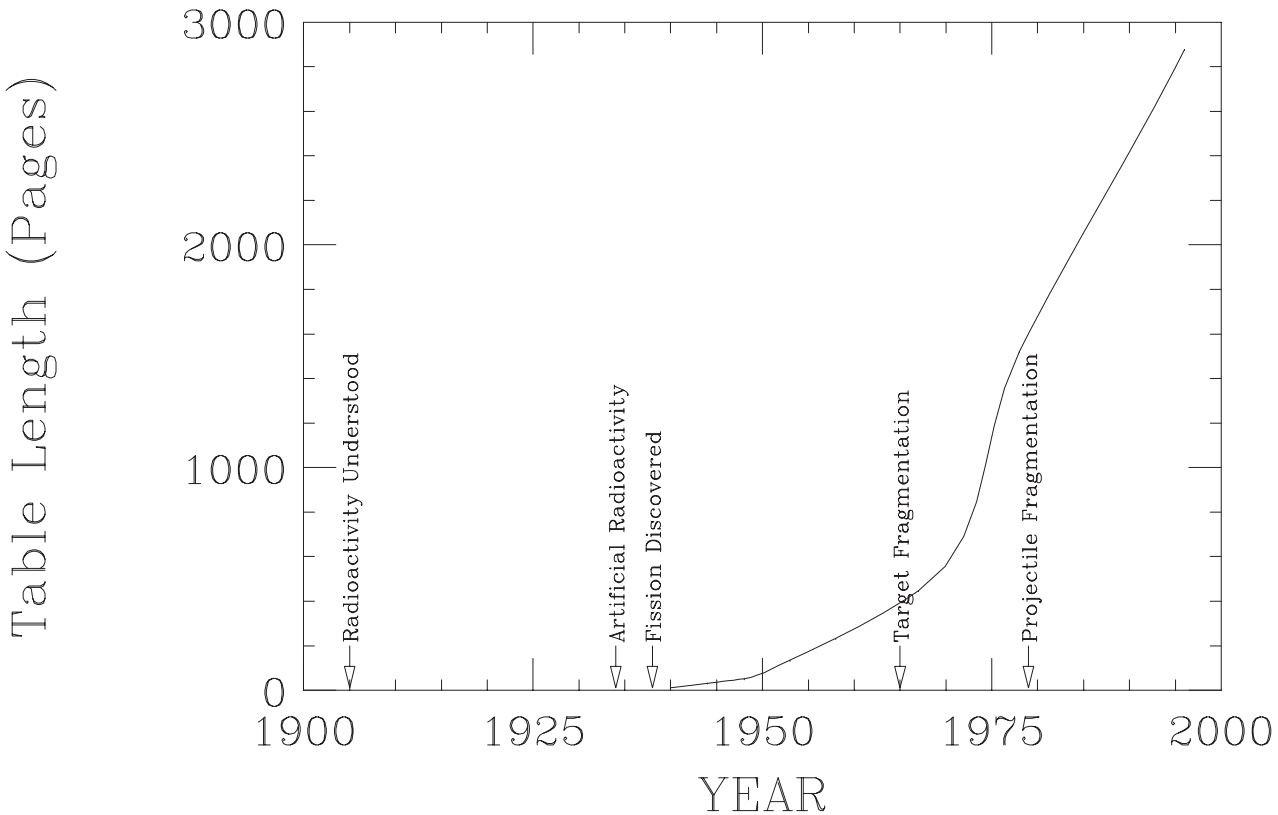


U. Müller *et al.*,
Phys. Rev. C**30**, 1199 (1984)

The march of time for The Table of Isotopes







What is an exotic nucleus?

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Normal Nucleus:

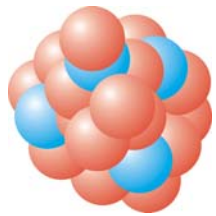
6 neutrons

6 protons (carbon)

^{12}C

Stable, found in nature

Exotic Nucleus:



16 neutrons

6 protons (carbon)

^{22}C

Radioactive, at the limit of nuclear binding

Characteristics of exotic nuclei: Excess of neutrons or protons, short half-life, neutron or proton dominated surface, low binding

One thing we thought we knew about nuclei

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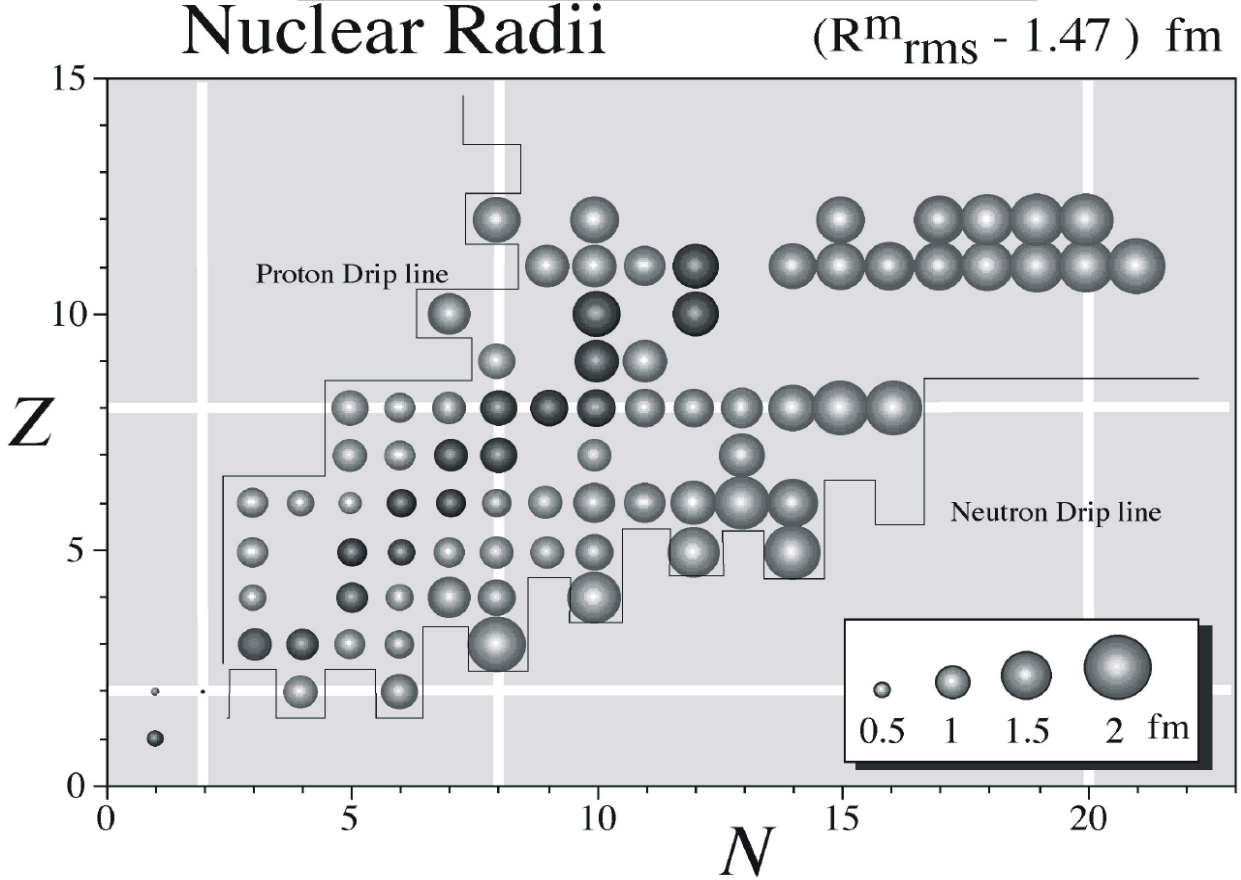
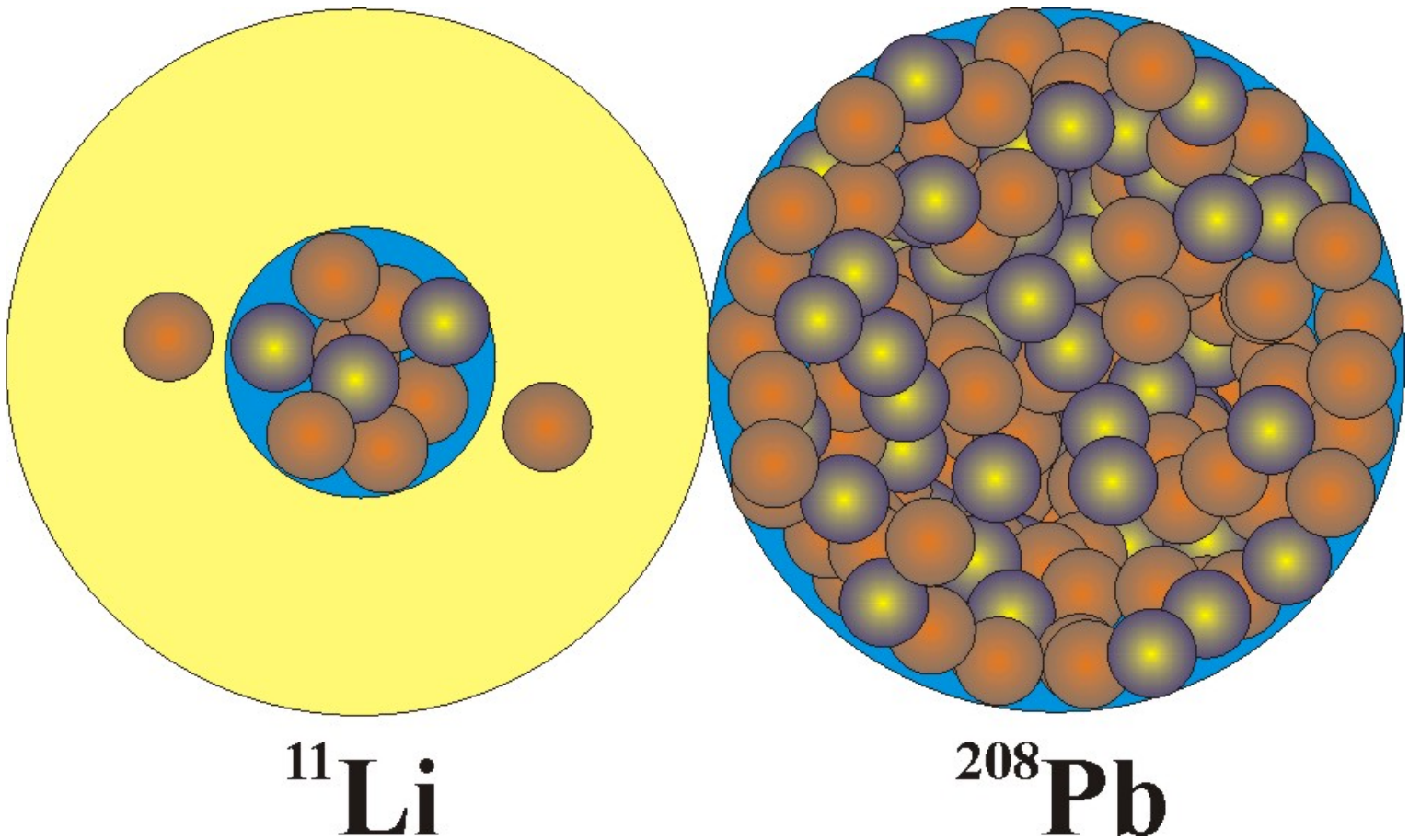
Textbooks: $R = r_0 A^{1/3}$



Halo Nuclei



Apollo 17 Crew, NASA

http://antwrp.gsfc.nasa.gov/apod/ap010204.html

Borromean Nucleus: ^{11}Li

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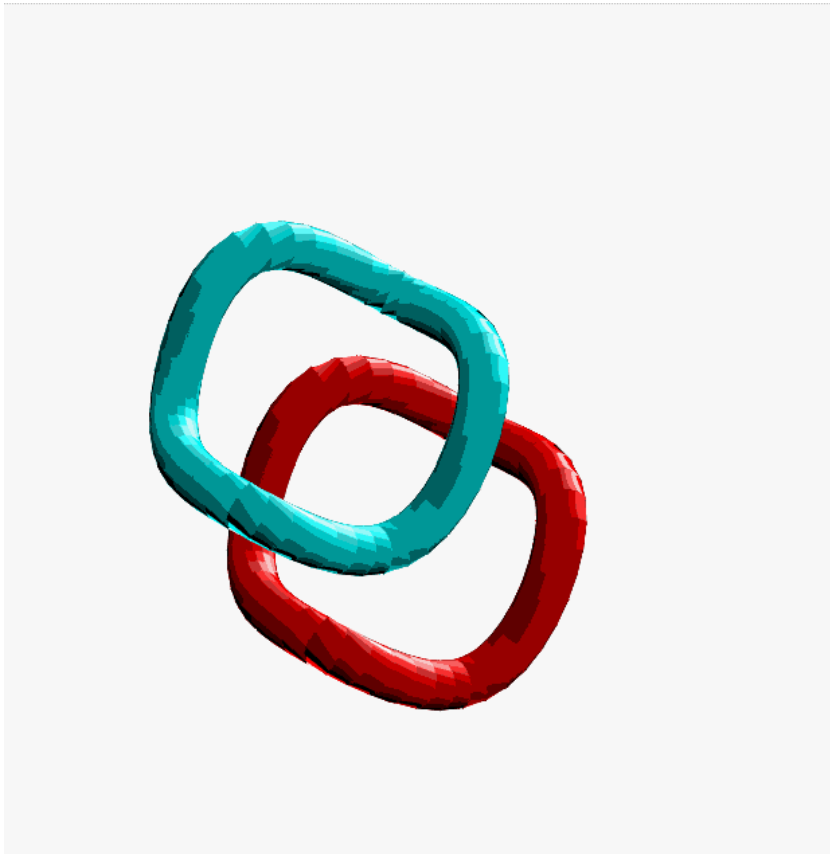
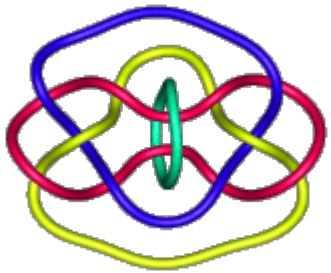
Neutron



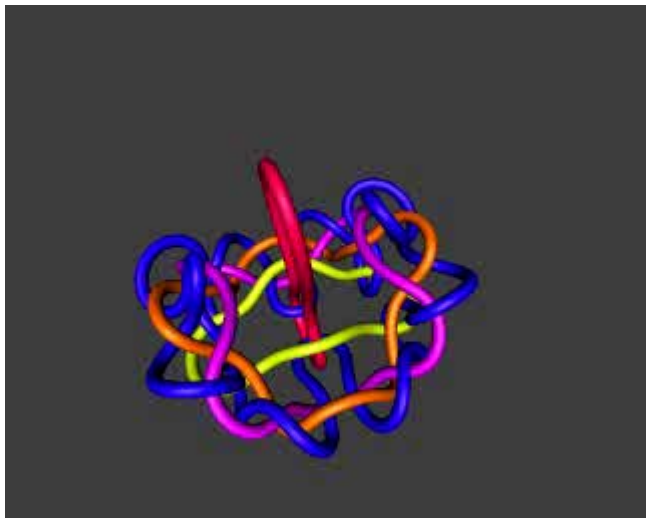
Neutron

^{9}Li

Brunnian Links

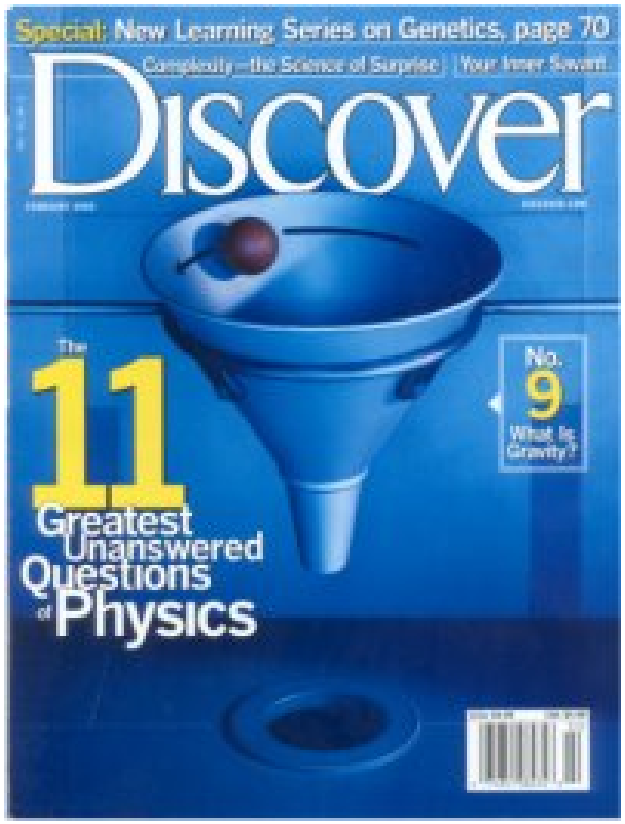


Robert Scharein
Department of Computer Science
University of British Columbia
http://www.cs.ubc.ca/nest/imager/contributions/scharein/brunnian/brunnian.html



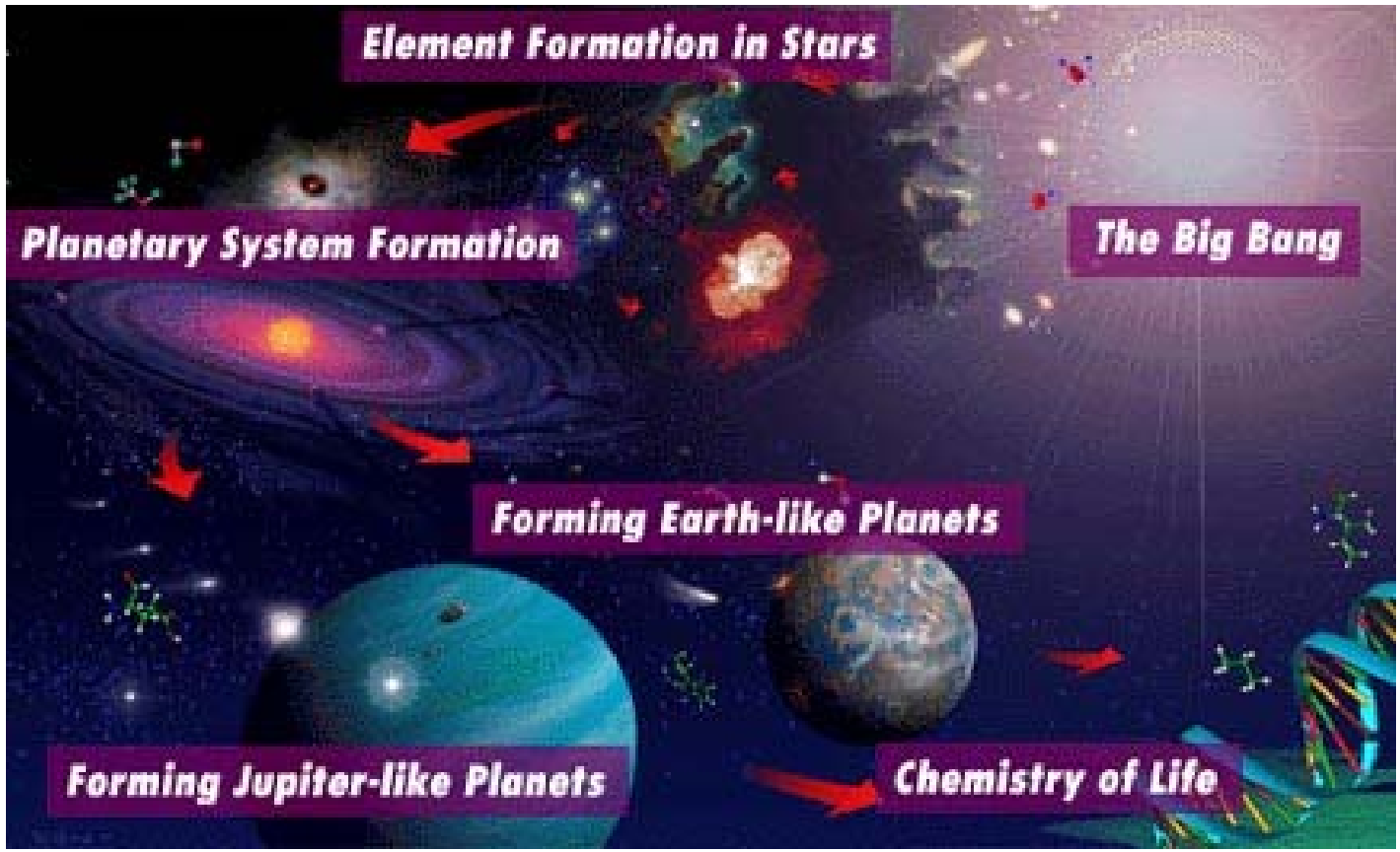
http://www.cs.ubc.ca/nest/imager/contributions/scharein/brunnian/brun6-rem3.mpg

Connecting Quarks to the Cosmos



1. What is dark matter?
2. What is dark energy?
3. How were the heavy elements from iron to uranium made?
4. …..

NASA: Timeline of the Universe



The Origin of the Elements

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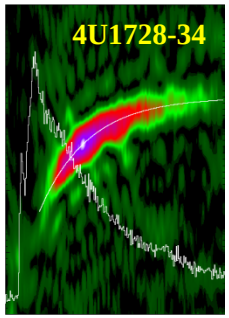
X-ray burst (RXTE)



RIA intensities (nuc/s)

- $> 10^{12}$
- 10^{10}
- 10^{6}
- 10^{2}
- 10^{-2}
- 10^{-6}

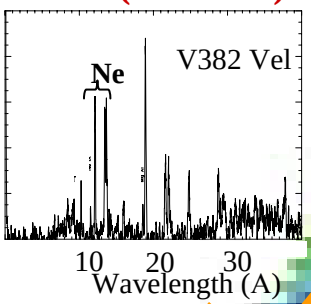
p process

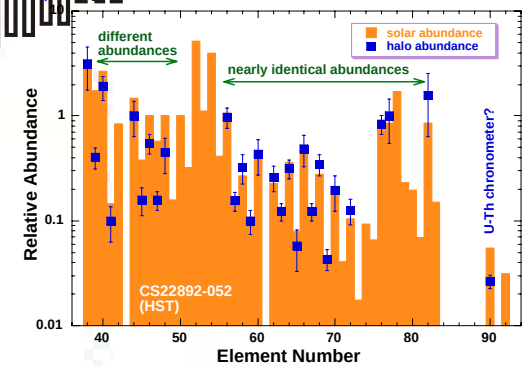
r process

rp process

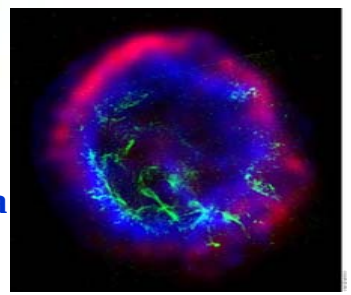
EC

Nova (Chandra)





Metal poor halo star (Keck, HST)



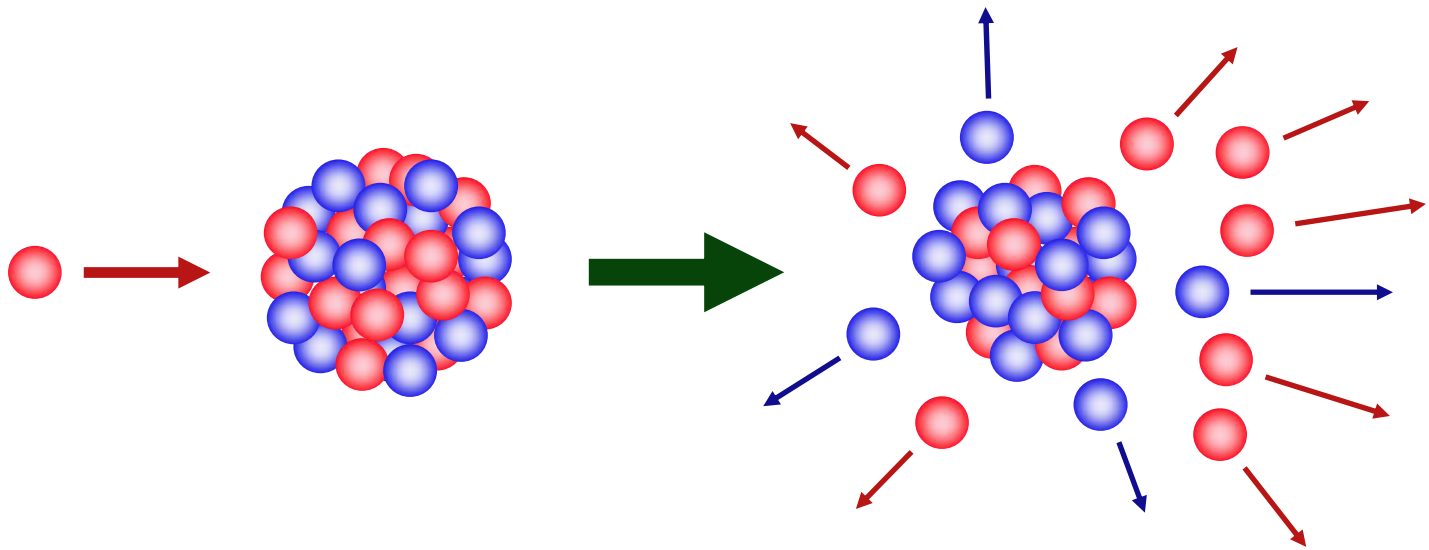
Supernova (HST)

protons

neutrons

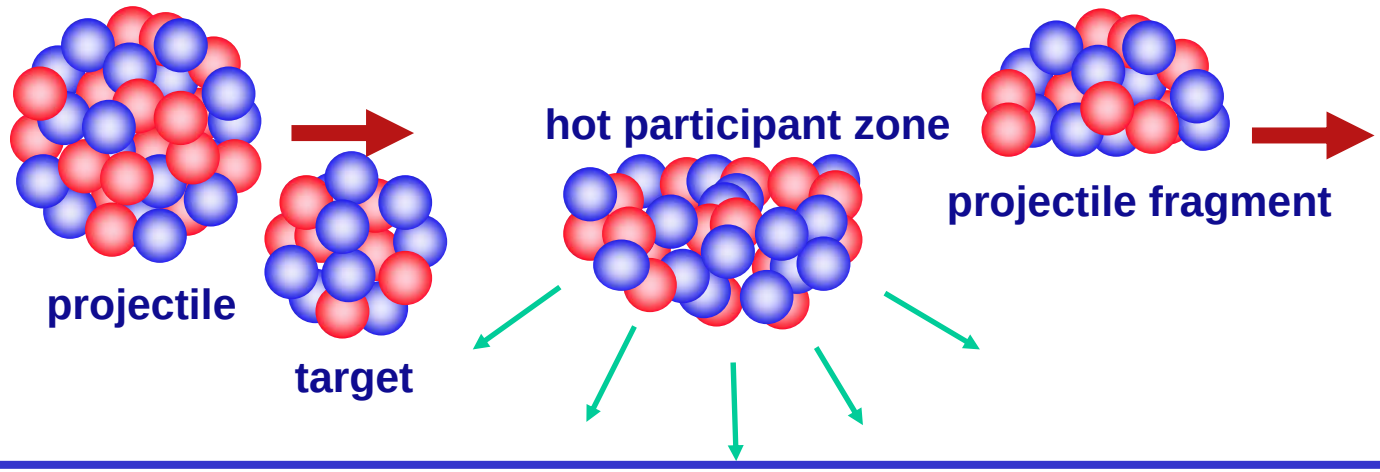
Target Fragmentation

Random removal of protons and neutrons from heavy target nuclei by energetic light projectiles (pre-equilibrium and equilibrium emissions).

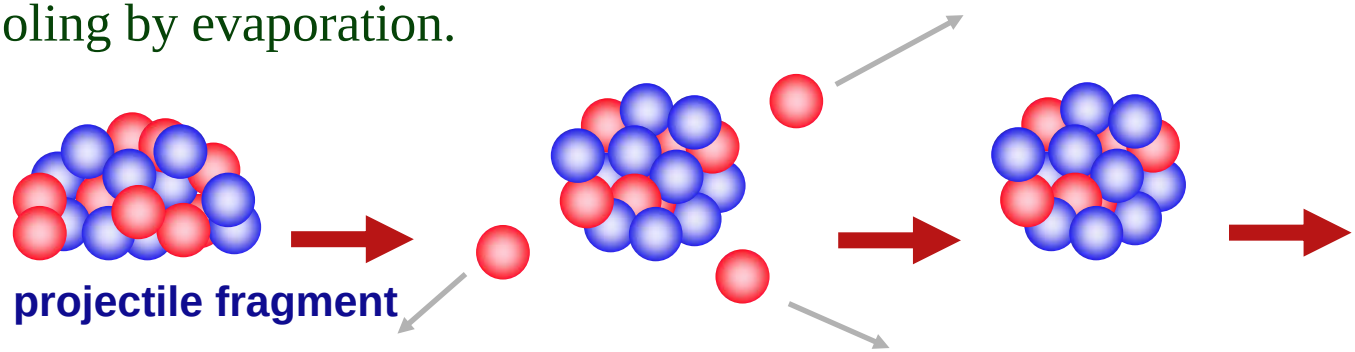


Projectile Fragmentation

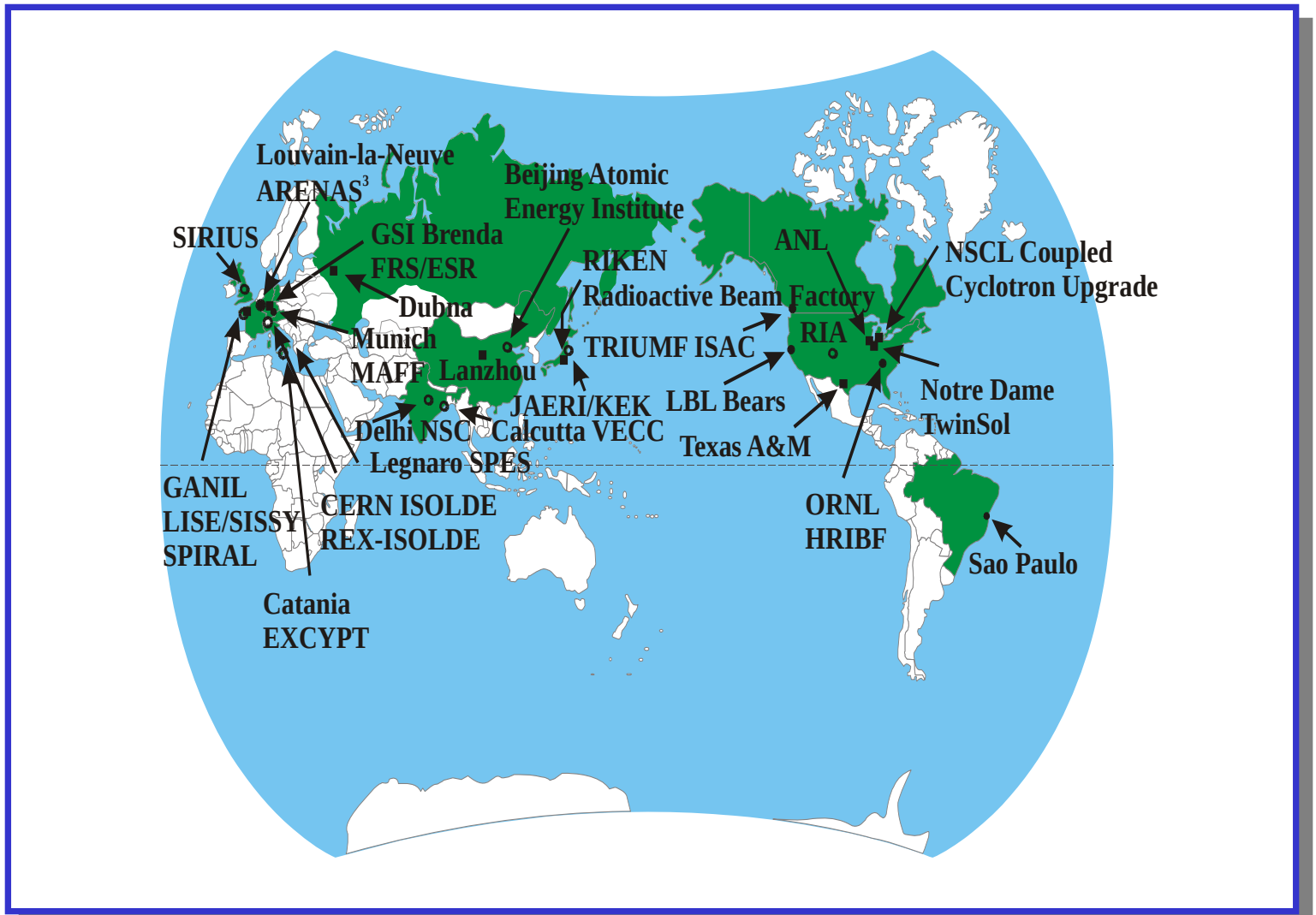
Random removal of protons and neutrons from heavy projectile in peripheral collisions



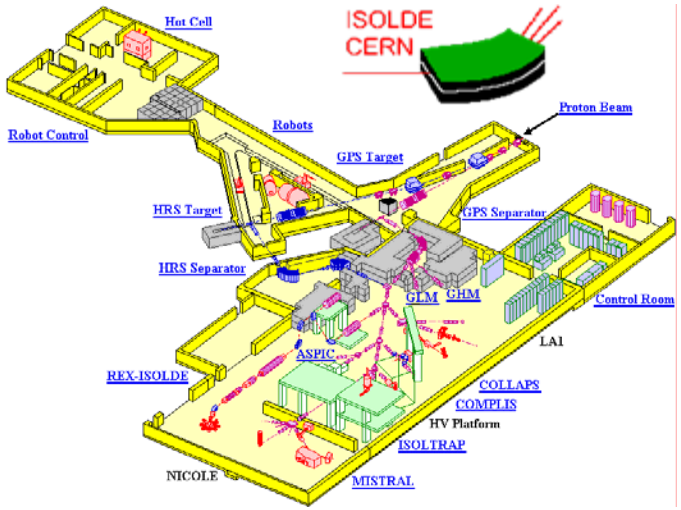
Cooling by evaporation.

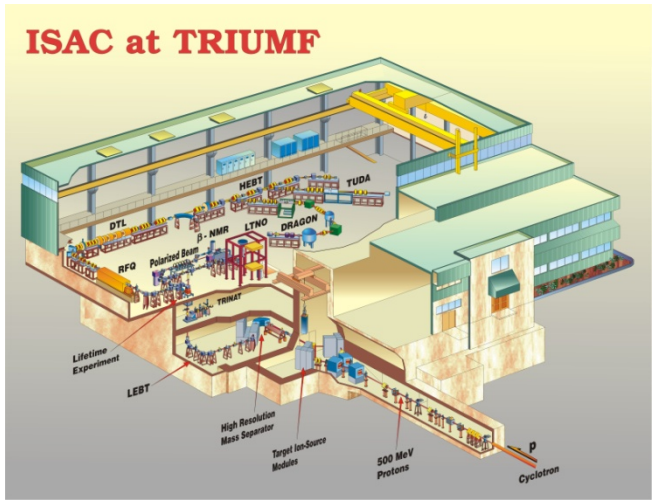


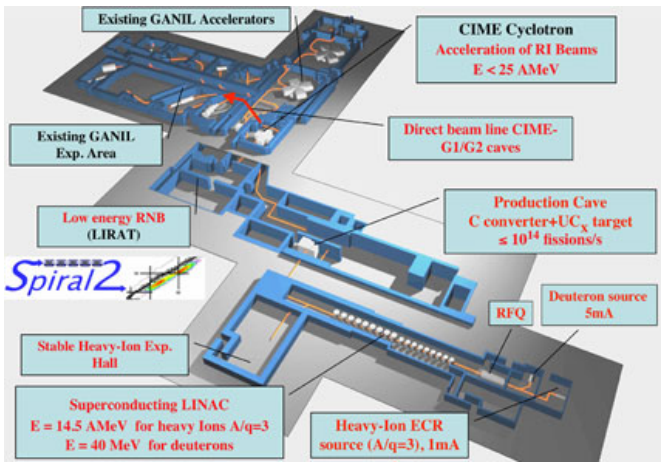
World Wide Effort in RIB Science

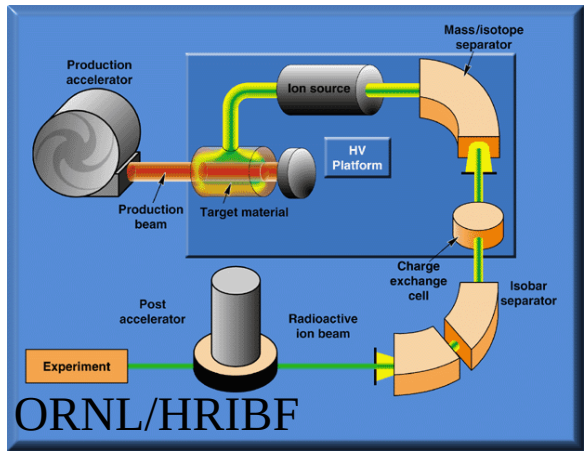


Plans/Projects at Target Fragmentation Facilities

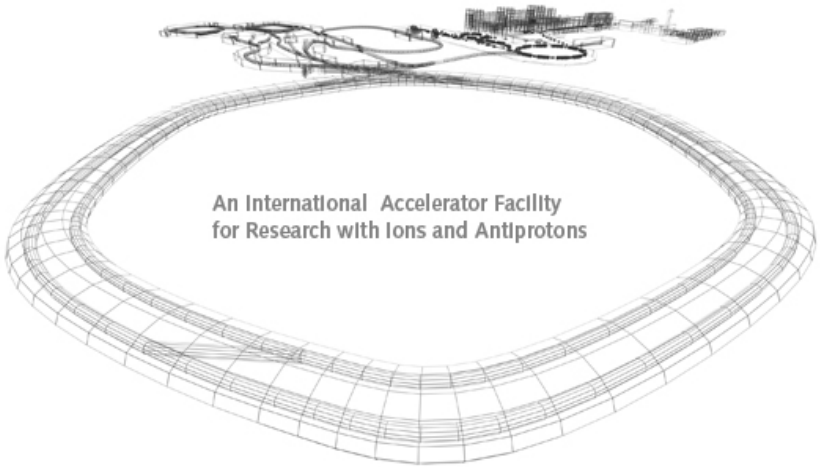






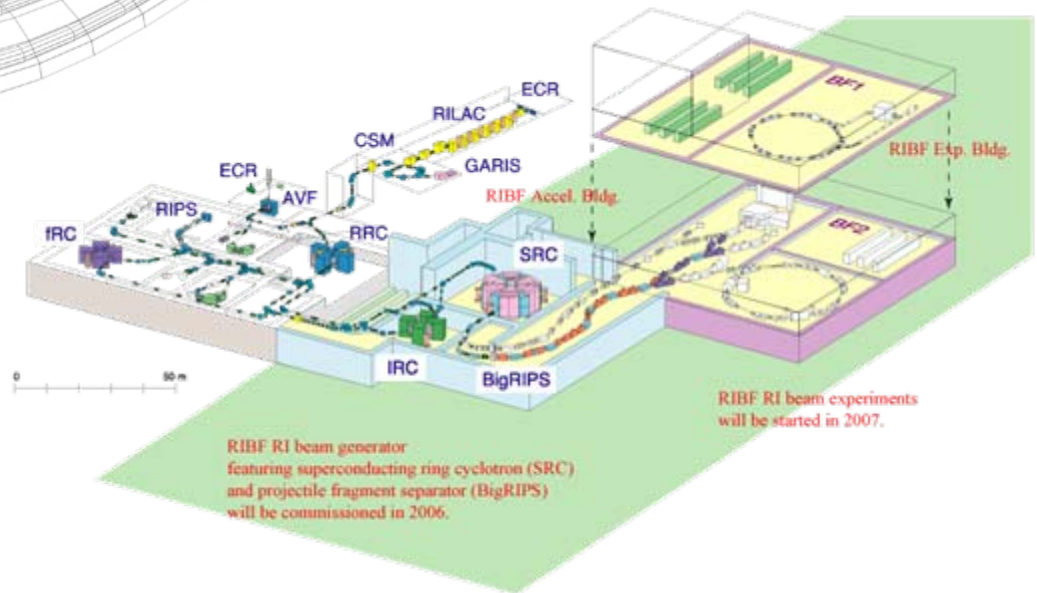


Plans/Projects at Fragmentation Facilities



FAIR

GSI, Germany



RI Beam Factory

RIKEN, Japan

National Superconducting Cyclotron Laboratory

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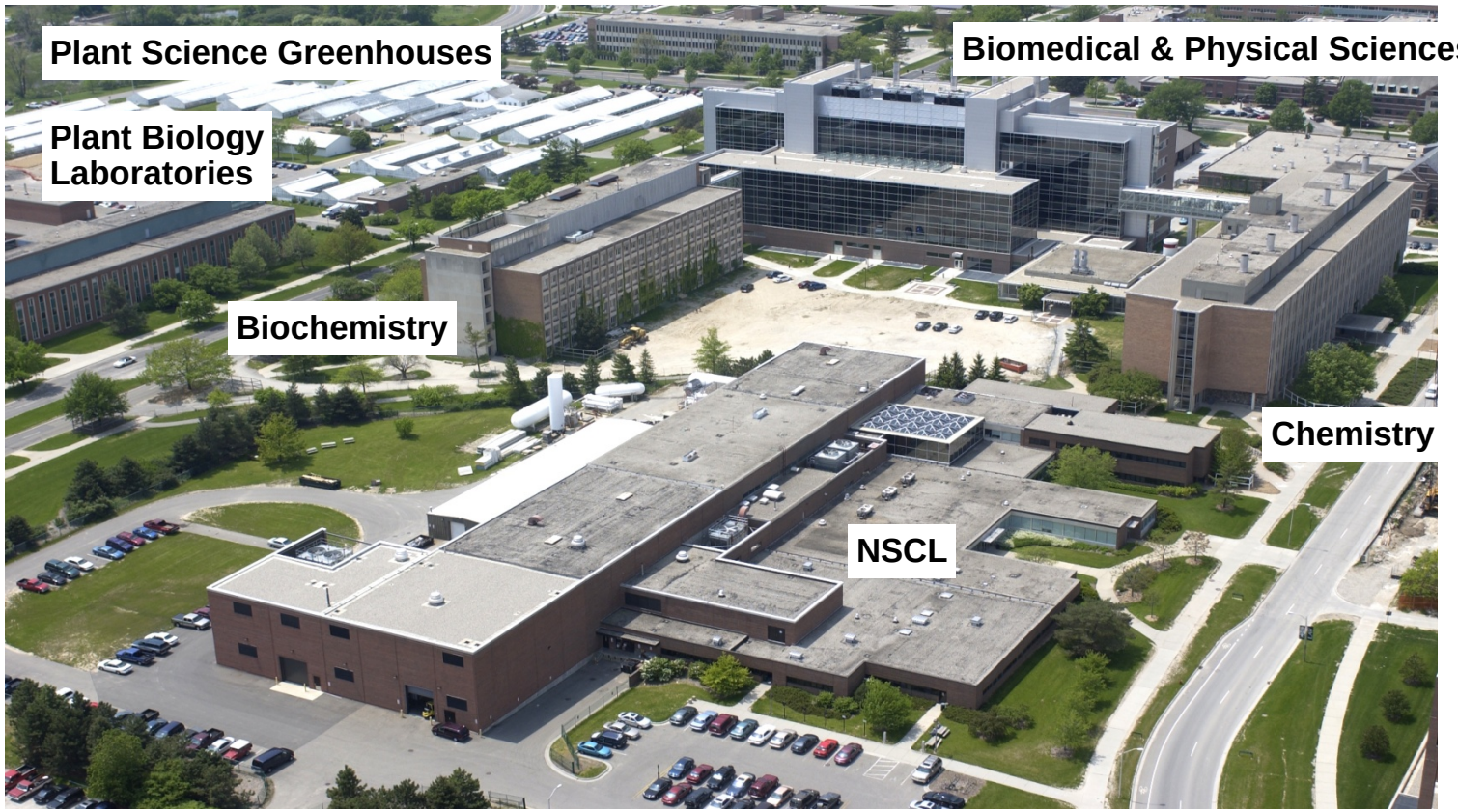

Nuclear science, astro-nuclear physics, accelerator physics, and societal applications

NSCL

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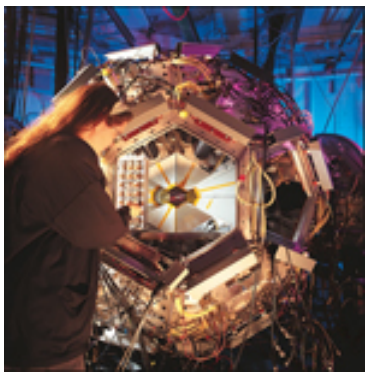
- 295 Employees
  - Faculty of 29 physicists and chemists
  - Technical staff of over 150 employees
  - 52 graduate and 48 undergraduate students
  - Over 675 separate users to date from over 143 organizations worldwide



- Nuclear physics graduate program ranked #1 in nation where rare isotope research is conducted (#2 overall)

Coupled Cyclotron Facility

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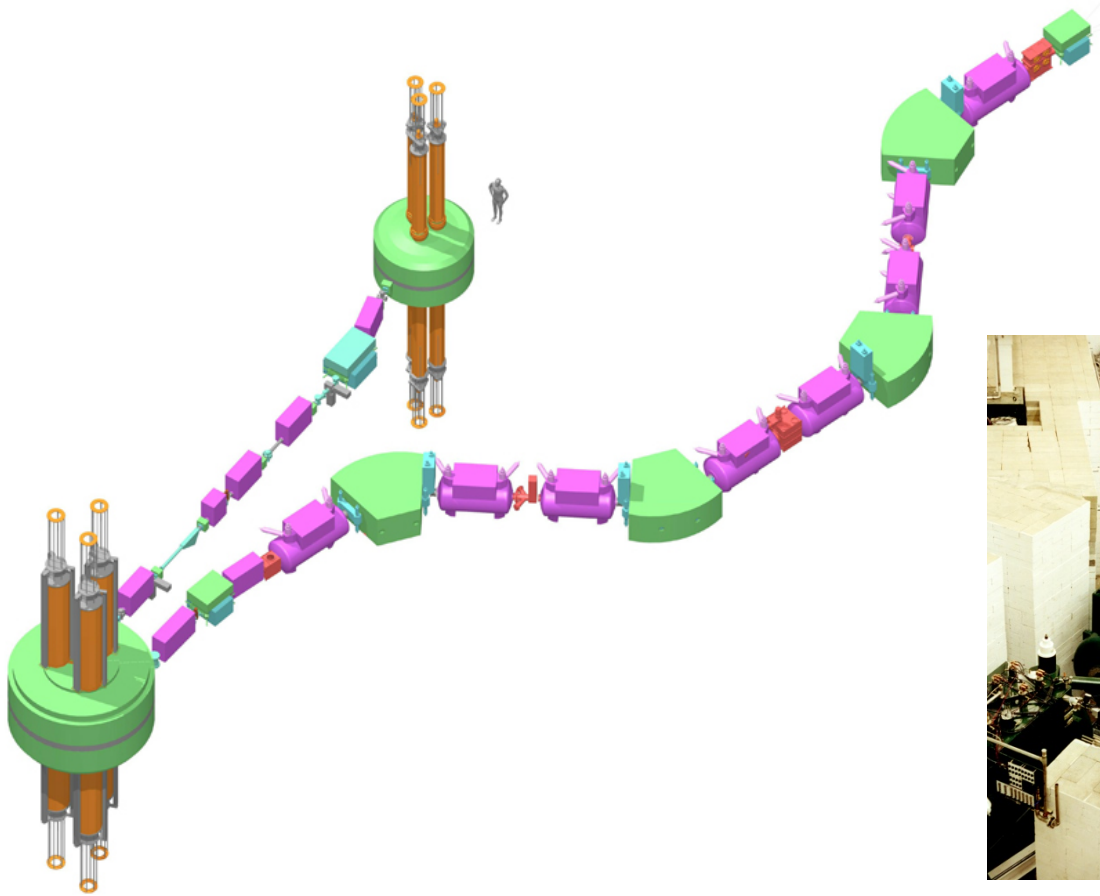
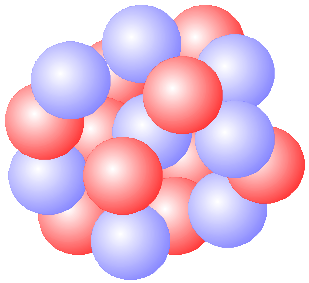
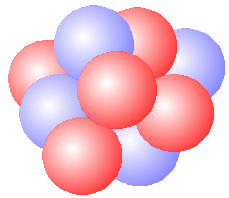


Fragmentation Reaction

^{18}O beam



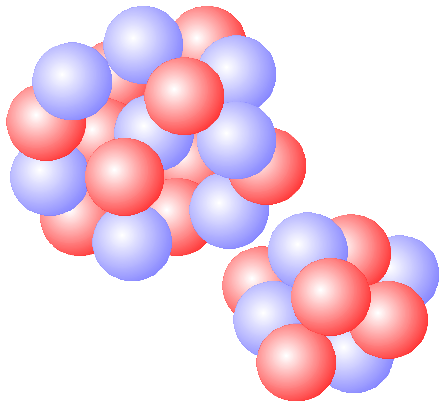


^{9}Be target

t = -10^{-22} sec
d = -10 fm
.000000000000039''

---

^{18}O

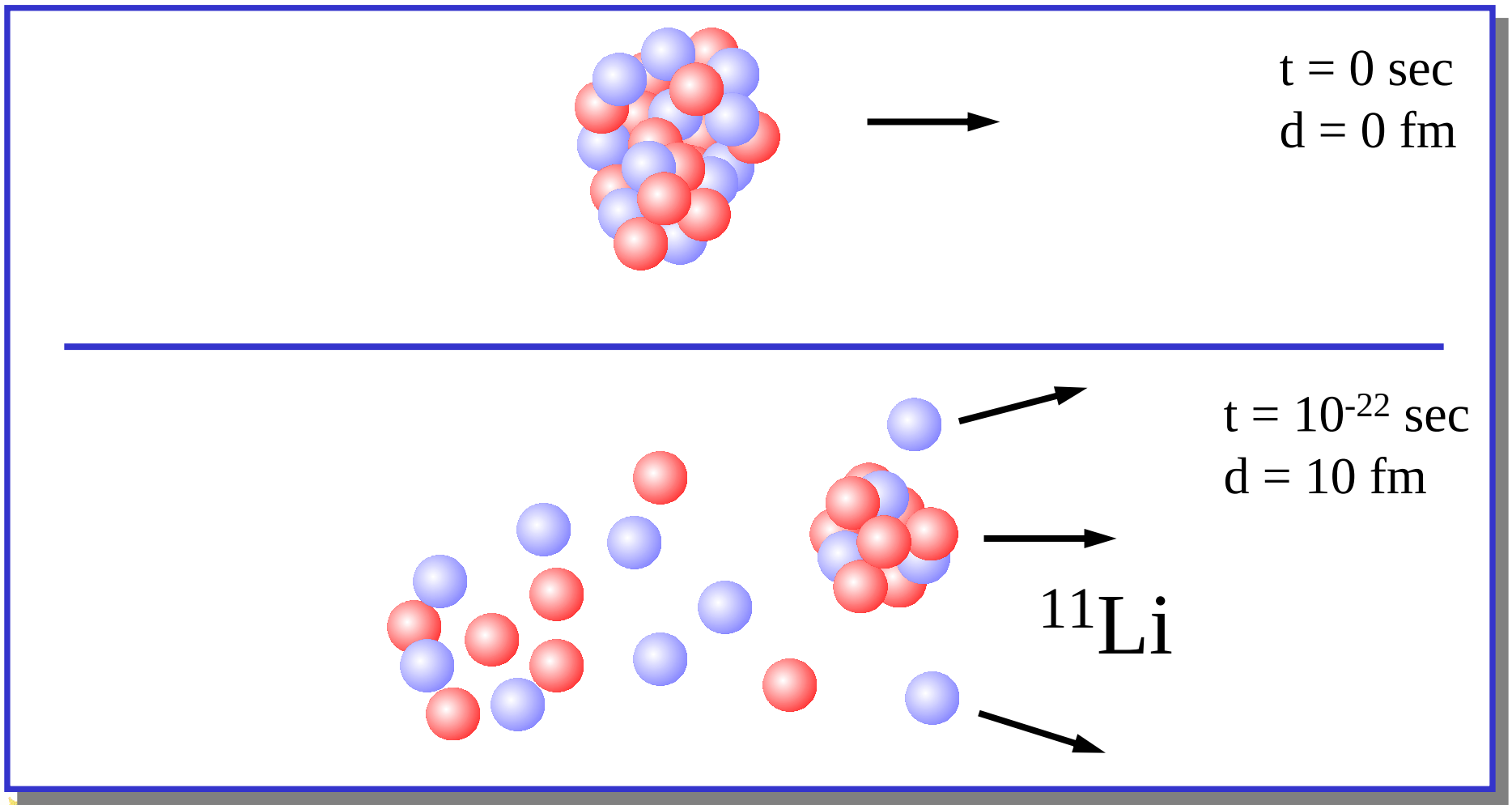


^{9}Be

t = -5x10^{-23} sec
d = -5 fm

80 MeV/nucleon
40% speed of light
278,000,000 mph

Production of ^{11}Li



Definitions/Numbers

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1pnA, 80 MeV/nucleon, ^{18}O, 8^{+}

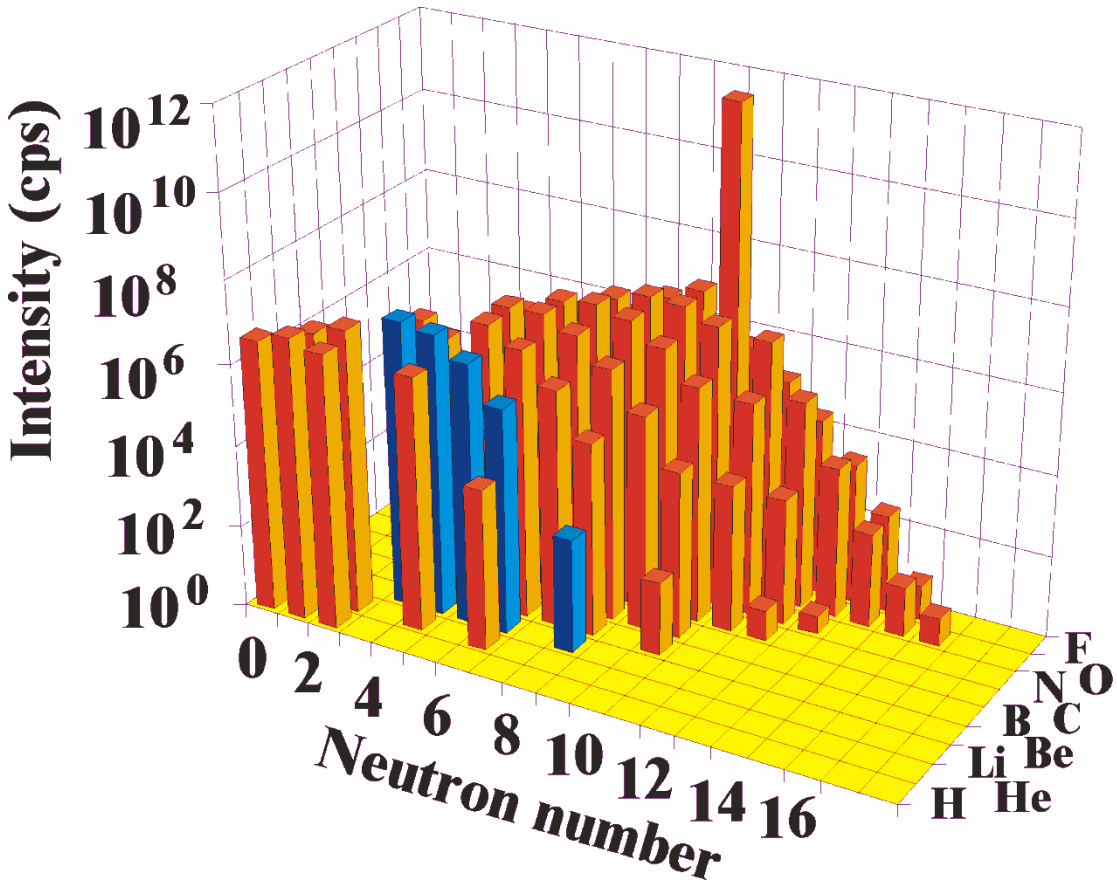
Energy

Energy per nucleon:	80 A MeV
Total energy:	1440 MeV
Momentum:	7096 MeV/c
Velocity:	11.7 cm/ns
	0.39 c
Rigidity: (p/q)	2.96 Tm

Beam Intensity

Particle Current:	1pnA
Electrical Current:	8enA
Particles:	6.25×10^{9}/s
Power:	1.44W

Production of Fragments



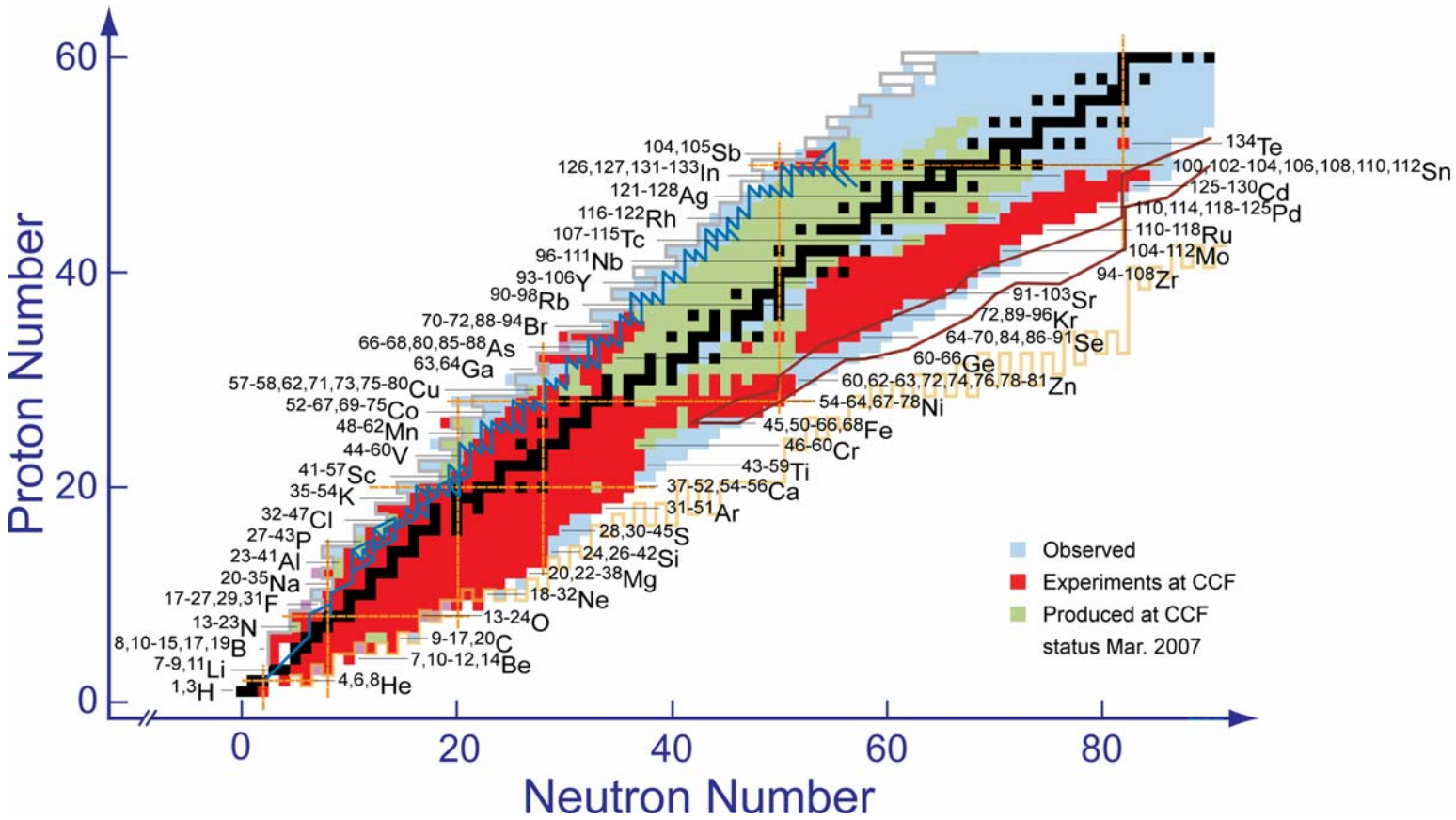
~10pnA ^{18}O

80 MeV/nucleon

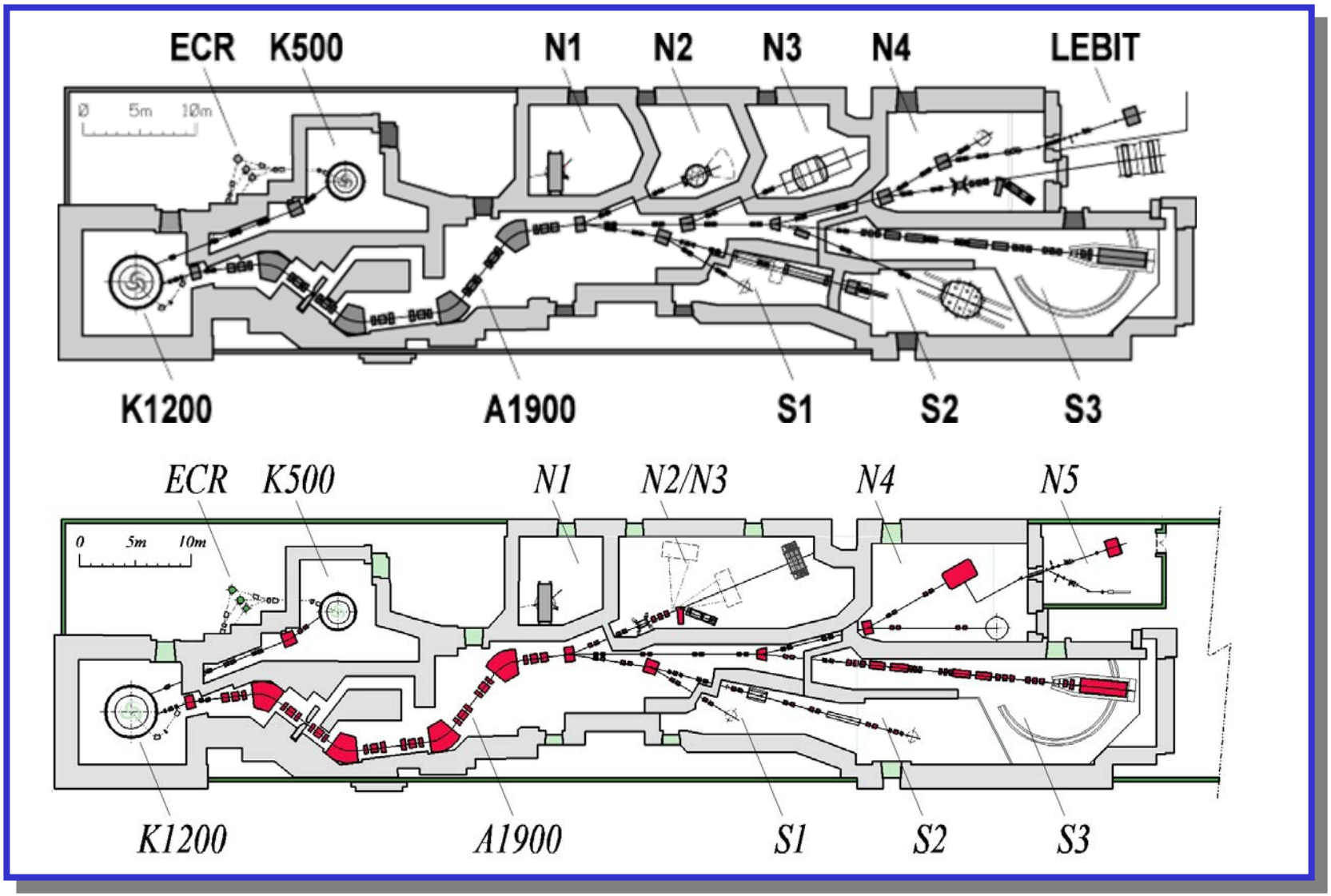
~100 ^{11}Li or

~$1/10^{9}$ $^{11}Li/^{18}O$

Beams Produced with CCF/A1900



Old and New NSCL Lay-out



Experimental Tools

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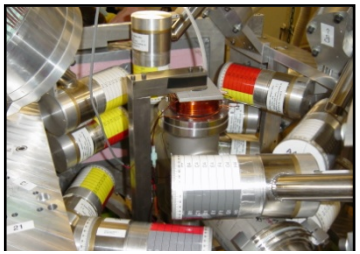
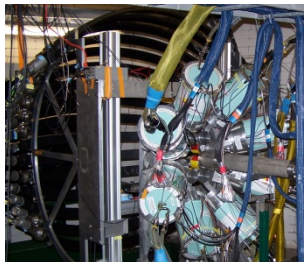


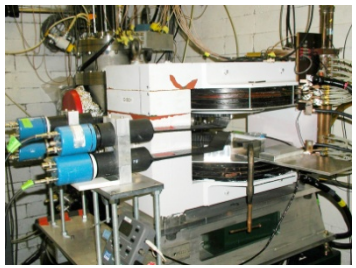
High Velocity Transient Field



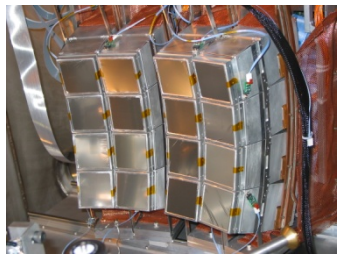
β-delayed neutrons

Knockout reactions

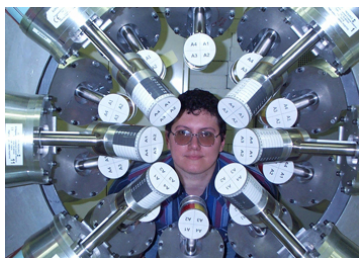
Masses



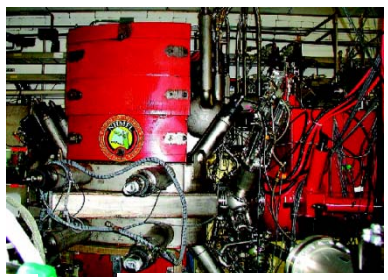
β-NMR



Transfer reactions



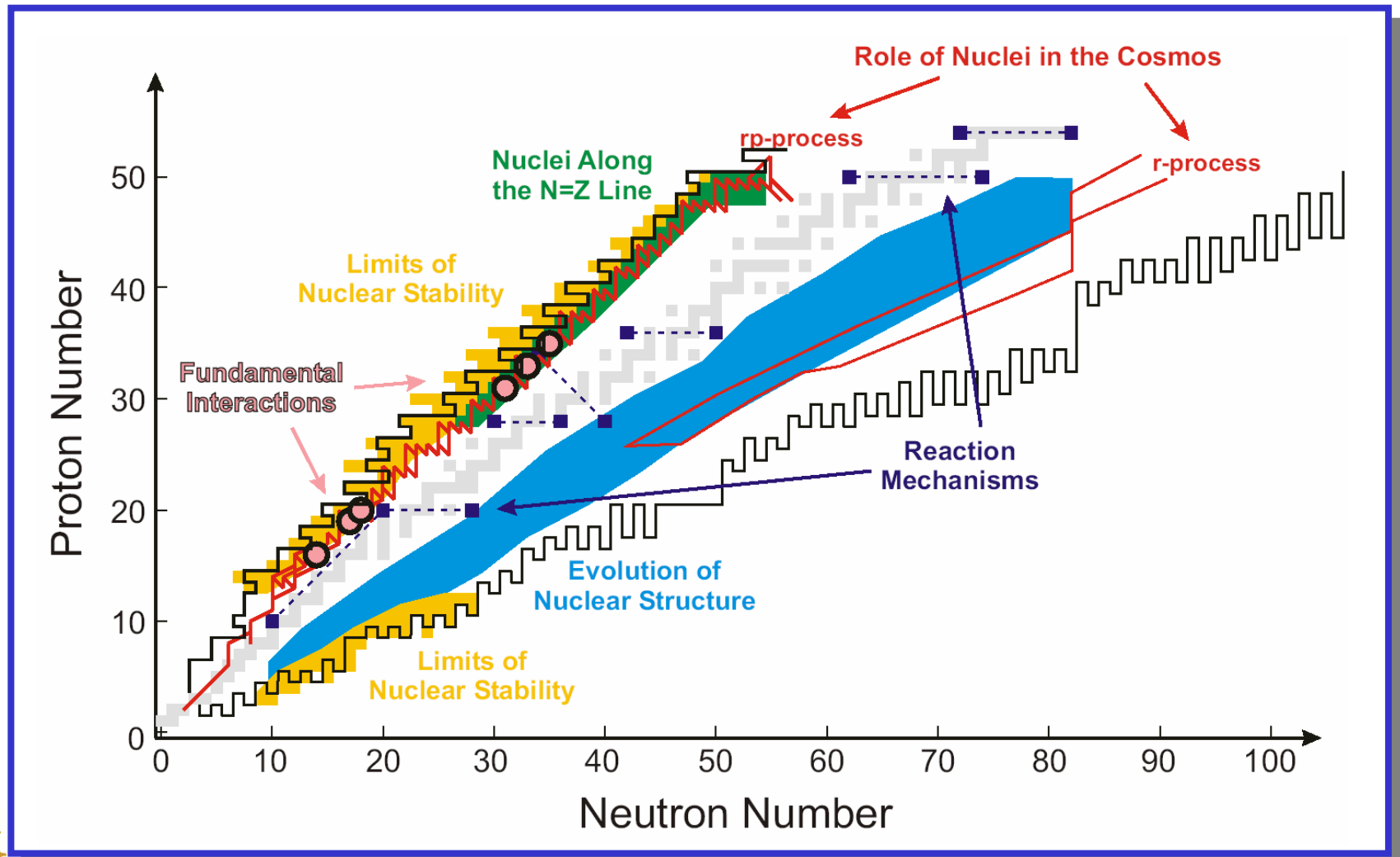
Coulomb excitation



Neutron Decay Spectroscopy

β-decay

Scientific Reach if the NSCL



The Future: Department of Energy 20-Year Science Facility Plan

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November 10, 2003

Energy Secretary Spencer Abraham Announces Department of Energy 20-Year Science Facility Plan

Sets Priorities for 28 New, Major Science Research Facilities

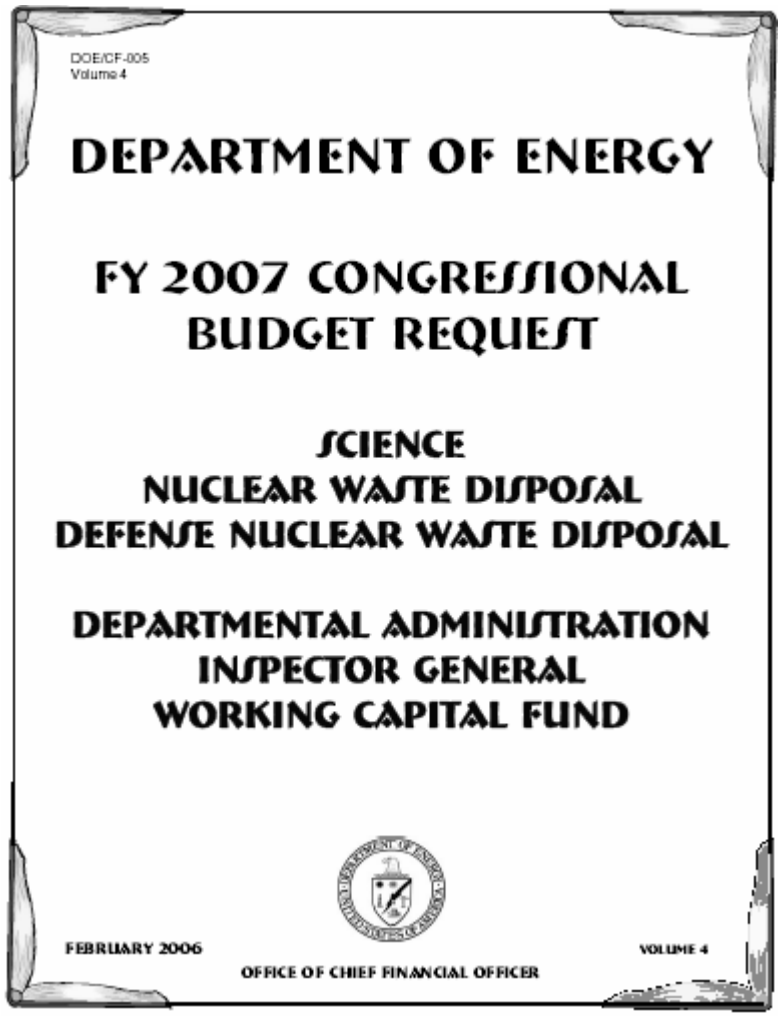
WASHINGTON, DC – In a speech at the National Press Club today, U.S. Energy Secretary Spencer Abraham outlined the Department of

RIA

Rare Isotope Accelerator

http://www.sc.doe.gov/Sub/Facilities_for_future/20-Year-Outlook-screen.pdf

FY 2007 Budget (Feb. 2006)


DOE/CF-005
Volume 4

DEPARTMENT OF ENERGY

FY 2007 CONGRESSIONAL BUDGET REQUEST

SCIENCE
NUCLEAR WASTE DISPOSAL
DEFENSE NUCLEAR WASTE DISPOSAL

DEPARTMENTAL ADMINISTRATION
INSPECTOR GENERAL
WORKING CAPITAL FUND

FEBRUARY 2006

VOLUME 4

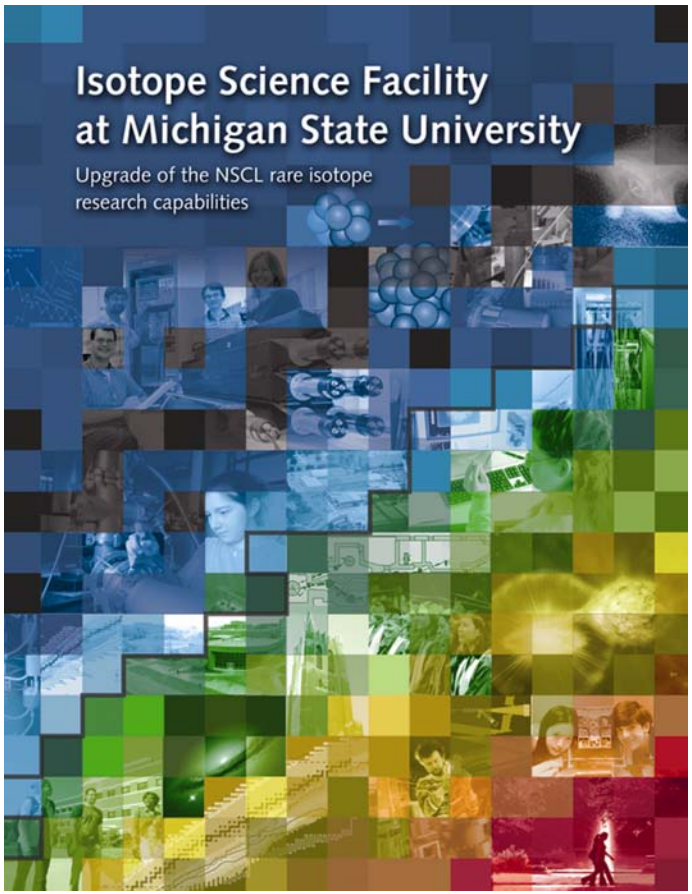
OFFICE OF CHIEF FINANCIAL OFFICER

Generic R&D in radioactive ion beam development, relevant for **next-generation facilities** in nuclear structure and astrophysics, is supported in FY 2007.

Statement by the Secretary of Energy

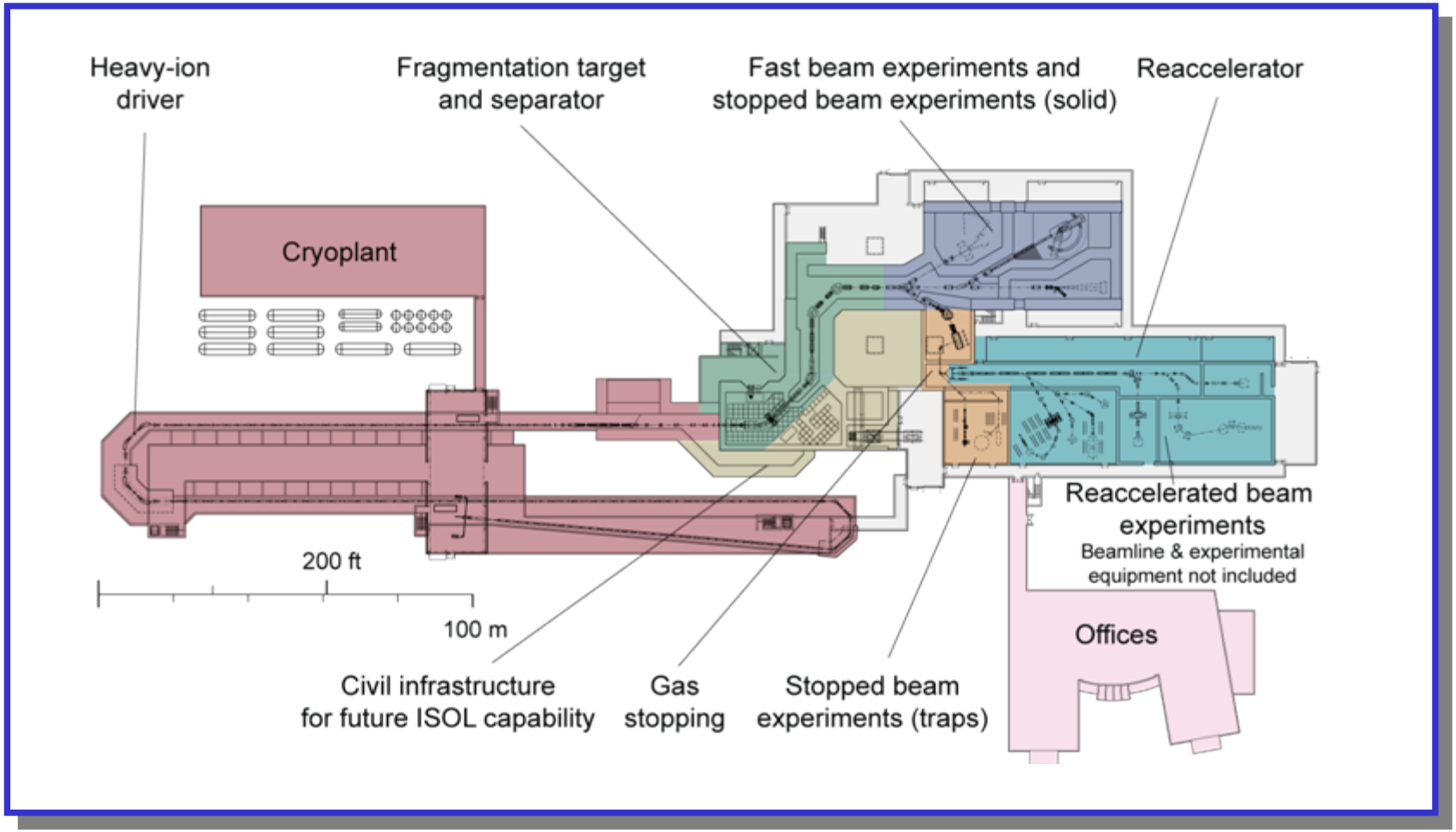
U.S. Secretary of Energy Samuel Bodman has informed Congress that the $1 billion Rare Isotope Accelerator (RIA) has been **delayed five years**. Bodman said R&D on RIA would continue with $5 to $6M budgeted per year until a preliminary engineering design could be prepared, **hopefully by 2011**.

Isotope Science Facility (ISF)

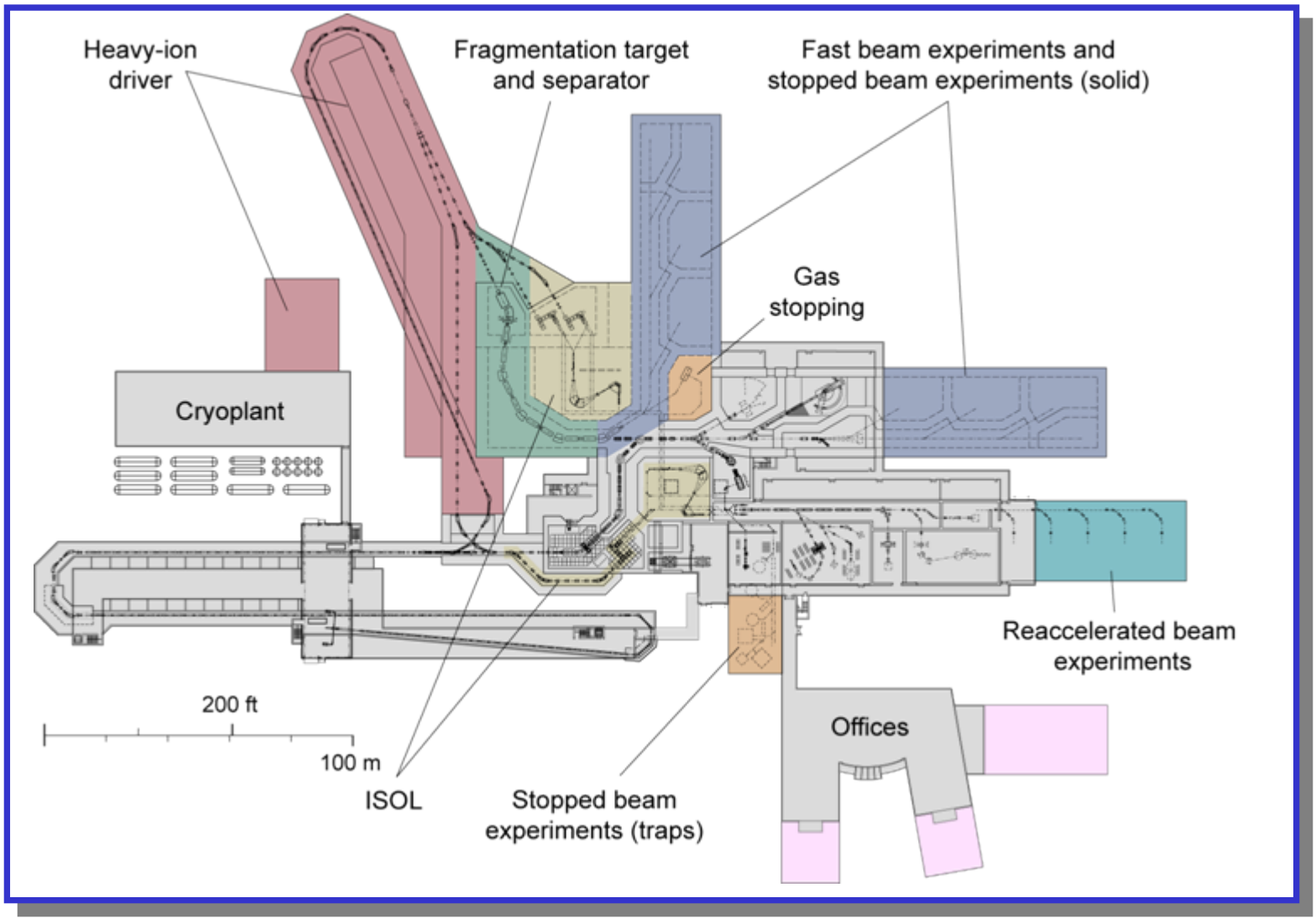


- The CCF at the NSCL has a strong rare isotope science program based on in-flight separation in the next decade
- State-of-the-art equipment and efficient operation will keep the NSCL competitive
- The NSCL needs a more powerful driver to ensure world-leading capabilities in the future
- The ISF upgrade is the next logical step that maintains flexible options for science driven upgrades
- The transition from the CCF to the ISF will allow the NSCL to maintain U.S. leadership in the field without disruption

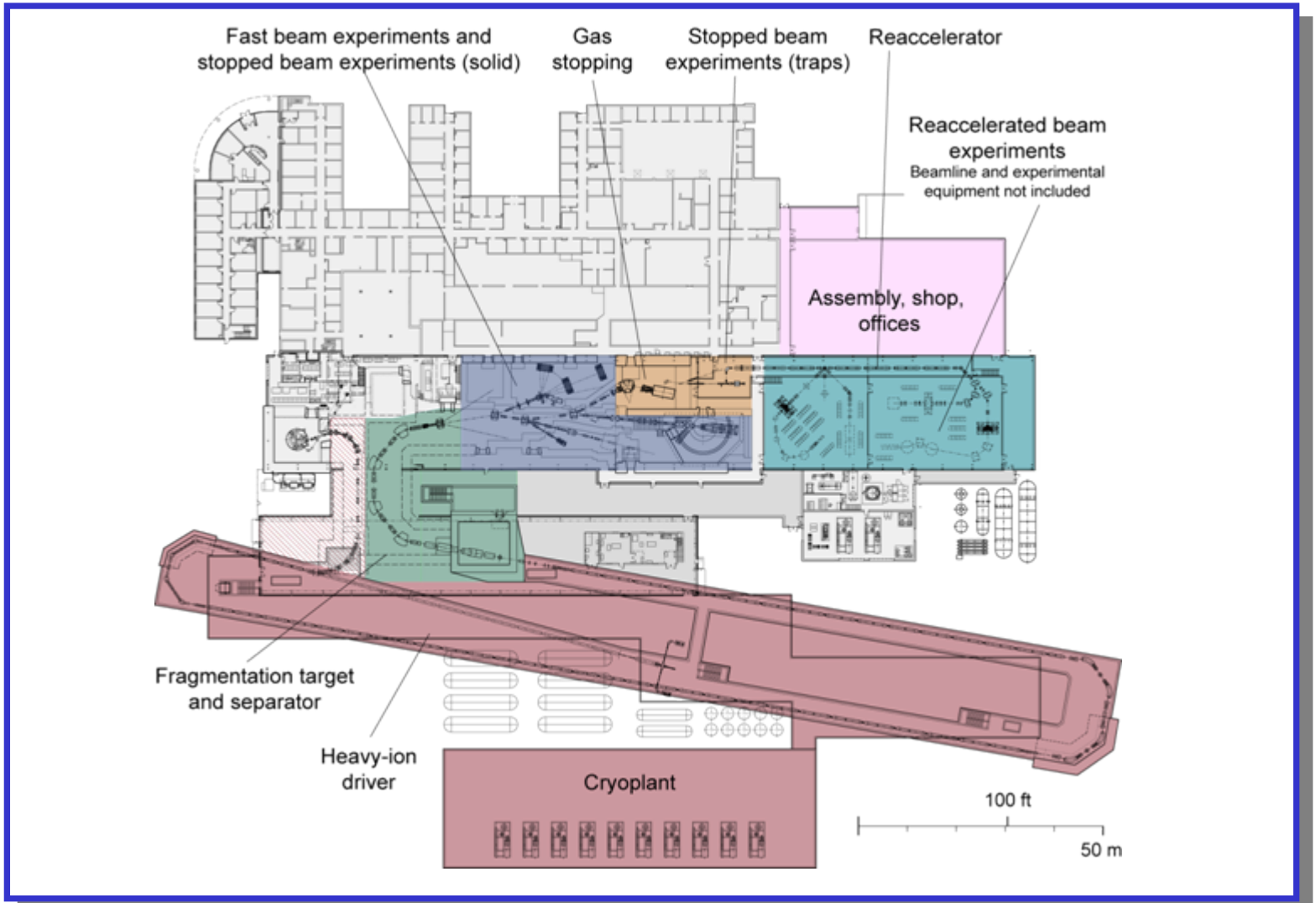
ISF Plan view (South Campus Site)



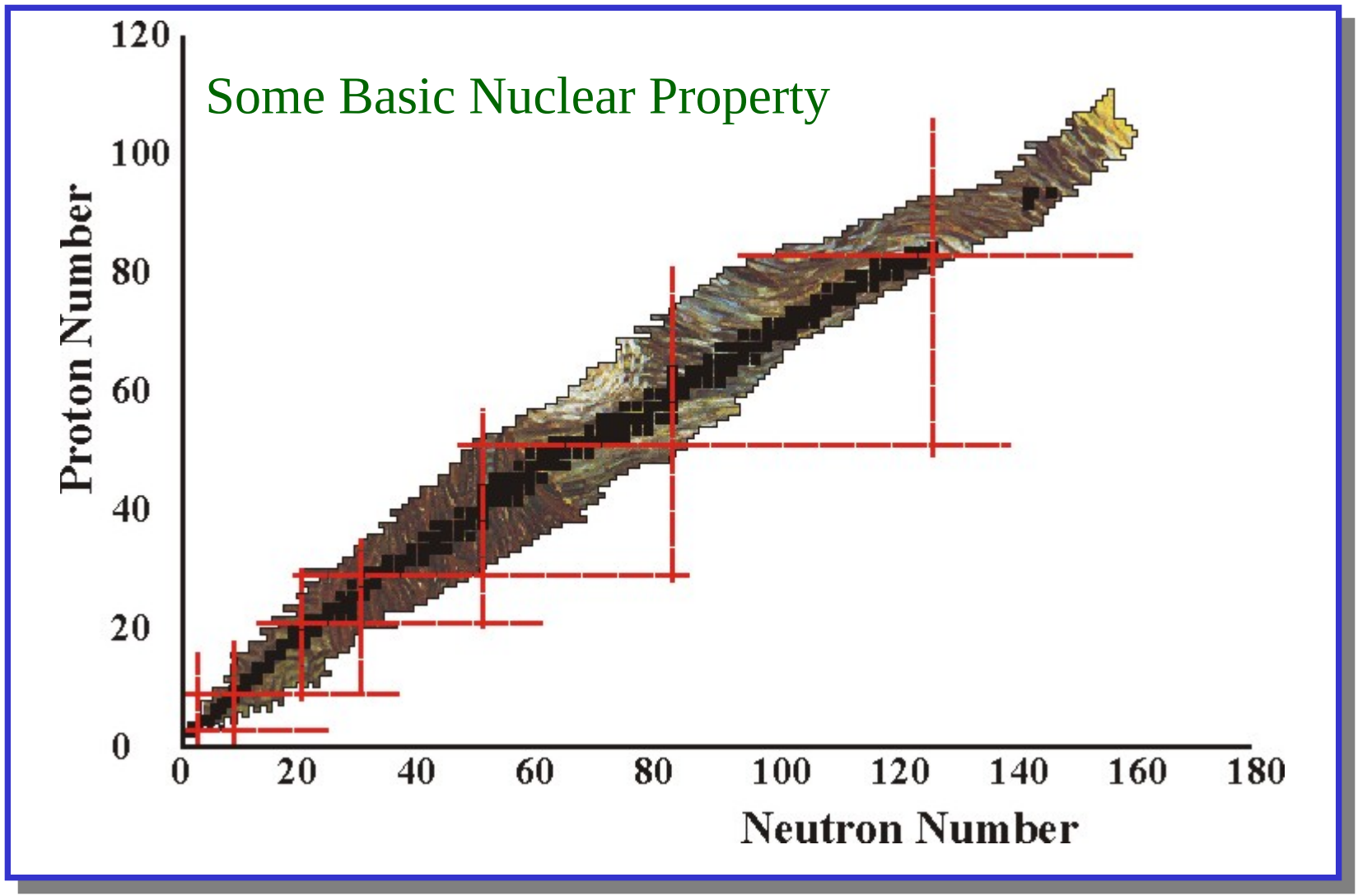
Future ISF Upgrade Options



ISF (NSCL Site Option)



At the moment we are limited in our view of the atomic nucleus



In the future we will greatly expand our horizons