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Importance and role of isotopes in basic research

Lee Riedinger

Professor of Physics
University of Tennessee
lrieding@utk.edu

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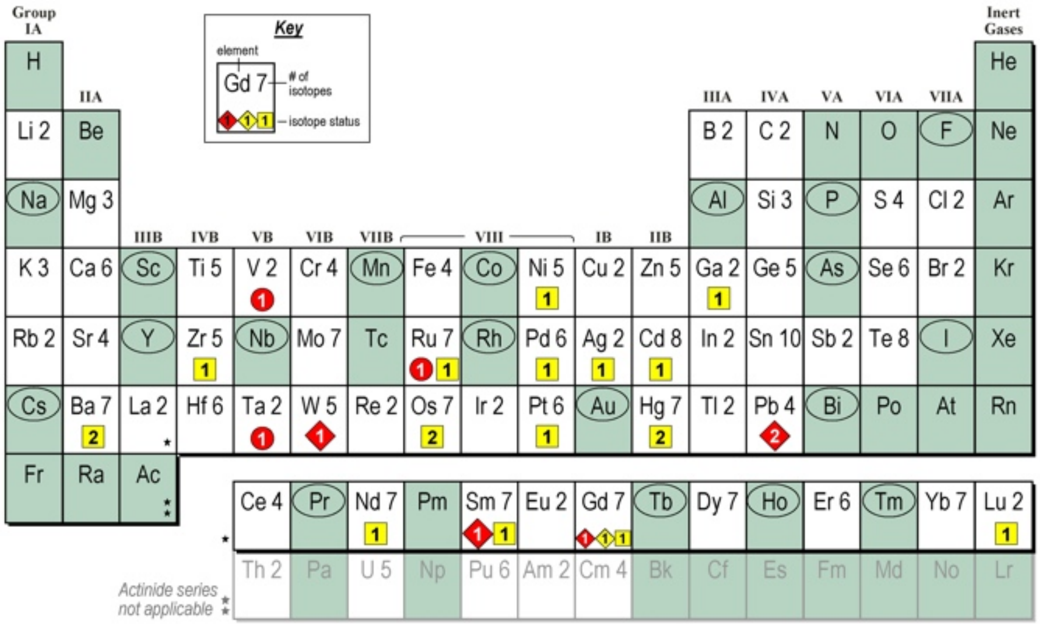
There are many uses of isotopes in research in various fields; some examples

1. Accelerator-based nuclear physics
2. Heavy water uses
3. National Ignition Facility
4. Mössbauer - geophysical and planetary uses
5. Fundamental symmetries
6. Nutrition
7. Isotopic reference materials
8. Nuclear medicine

Balance plethora of needs against availability and cost of isotopes

Map of *stable* isotopes available from DOE calutron program:

- White boxes - elements separated in calutrons
- Green boxes - can't be separated in calutrons
- Red - isotopes sold out
- Yellow - isotopes with limited supply



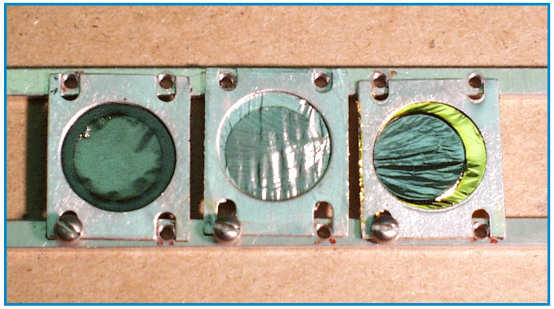
Isotopes are crucial for research in nuclear physics

- Research areas:
  - Nuclear structure
  - Dripline properties
  - Superheavy elements
  - Nucleosynthesis
- Major facilities - examples:
  - Atlas accelerator at Argonne National Laboratory
  - Holifield Radioactive Ion Beam Facility at Oak Ridge
  - National Superconducting Cyclotron Laboratory at Michigan State University
  - TUNL, Yale, Jefferson Lab, Florida State, Texas A&M, Notre Dame
- Future facilities:
  - CARIBU at Argonne - based on ^{252}Cf source
  - Facility for Rare Isotope Beams

Many stable and radioactive isotopes needed for accelerator-based nuclear physics

- Need targets made of many enriched stable isotopes, often the least abundant in nature.
- Need enriched isotopes to make beams, e.g., ^{48}Ca for heavy-element program at 88-inch cyclotron at Berkeley.
- Need isotopically enriched material for other uses:
  - Stripper foils
  - Charge resetting foils
  - Windows for gas cells used to produce secondary beams
  - Gas target windows
  - Target backing foils

GAMMASPHERE opened - 4π array of 110 γ-ray counters

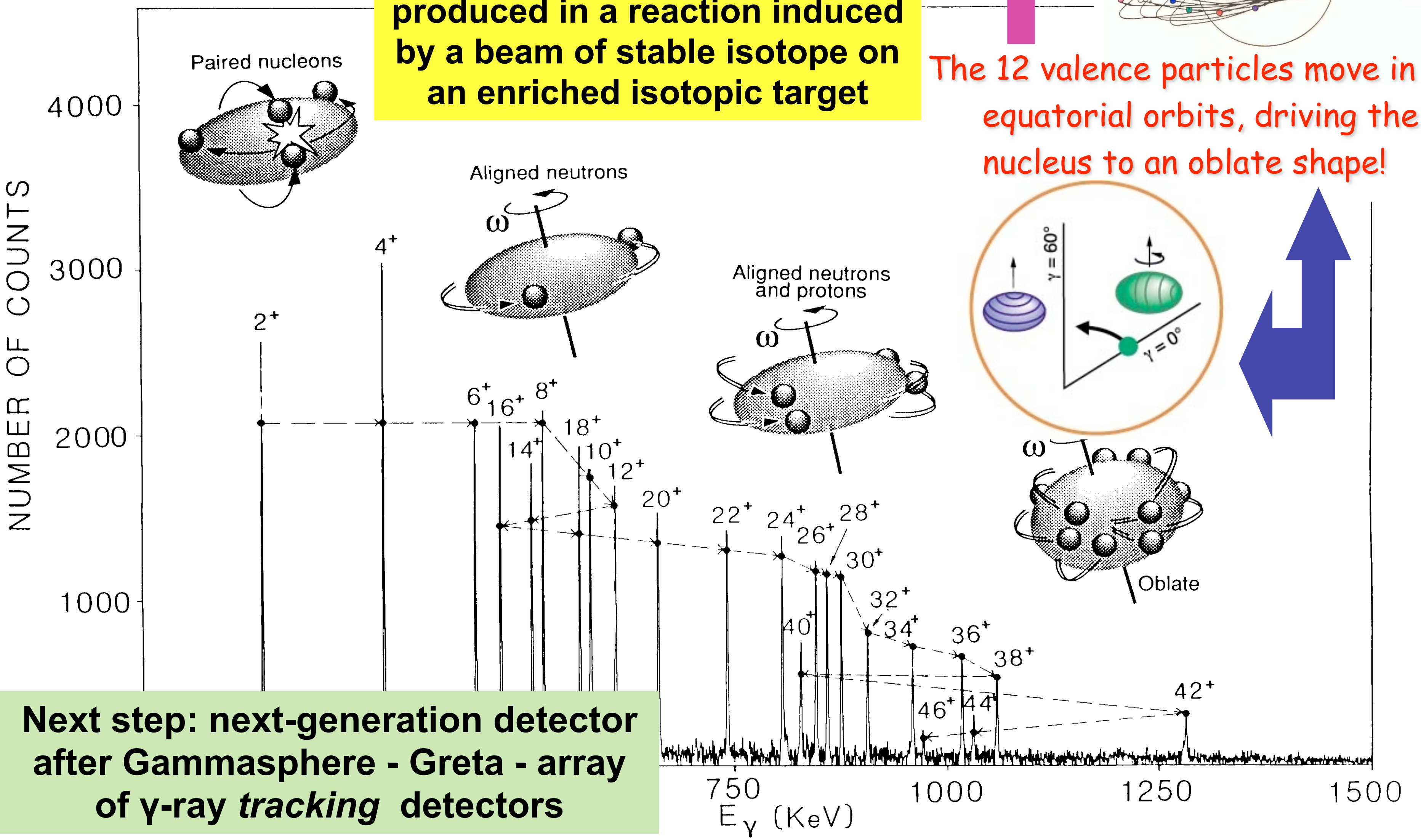


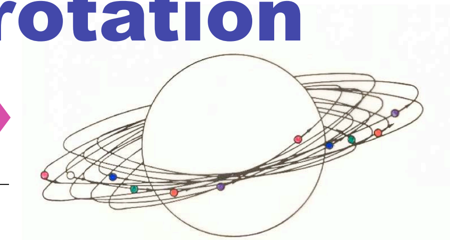
GAMMASPHERE target ladder with three ^{96}Ru targets on C, Al, and Au backing foils

Posters by John Greene, Jim Beene, Claude Lyneis, Andreas Stolz, Calvin Howell, James Symons, Bob Tribble

Gammasphere has been used to study nuclei in the extreme limit of fast rotation

Gamma-ray spectrum of ^{158}Er produced in a reaction induced by a beam of stable isotope on an enriched isotopic target



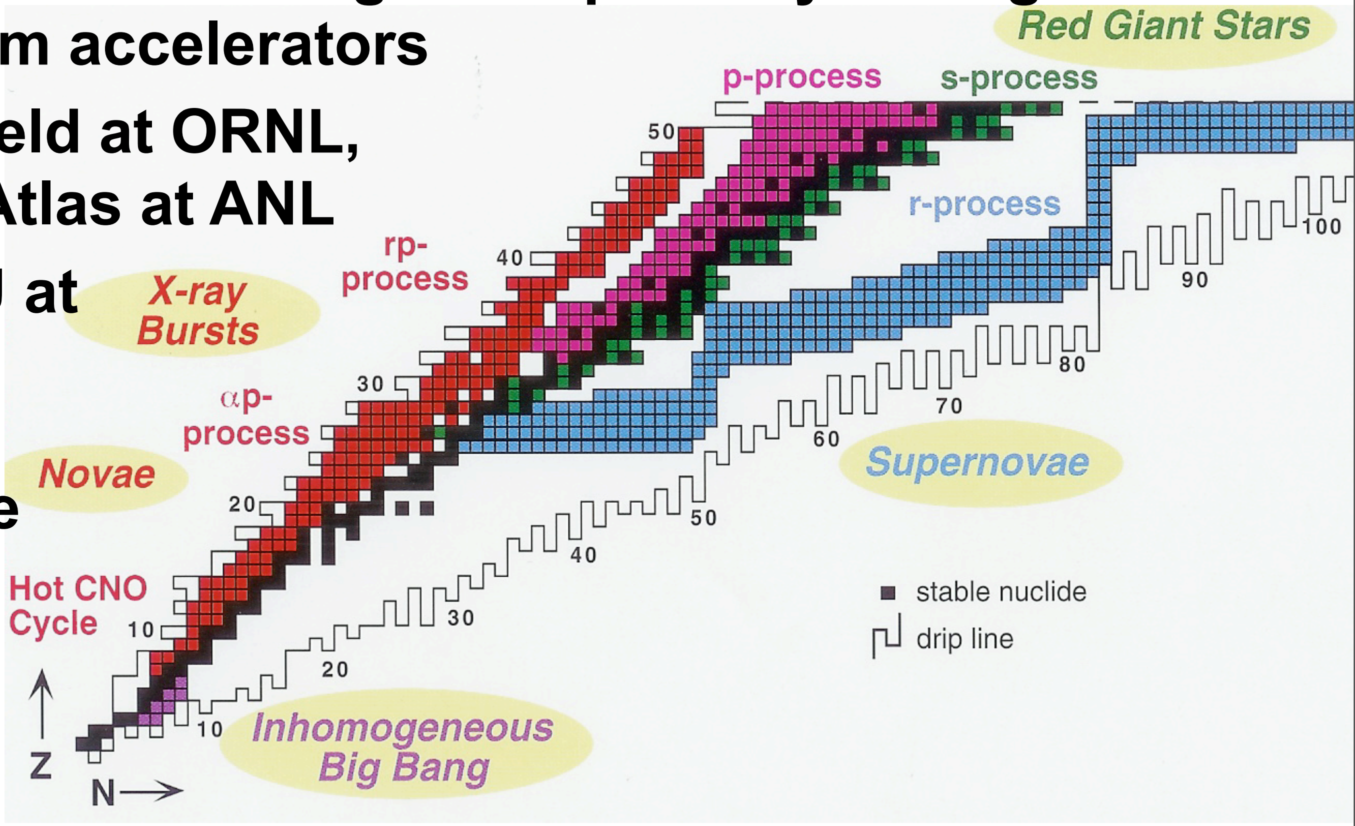


The 12 valence particles move in equatorial orbits, driving the nucleus to an oblate shape!

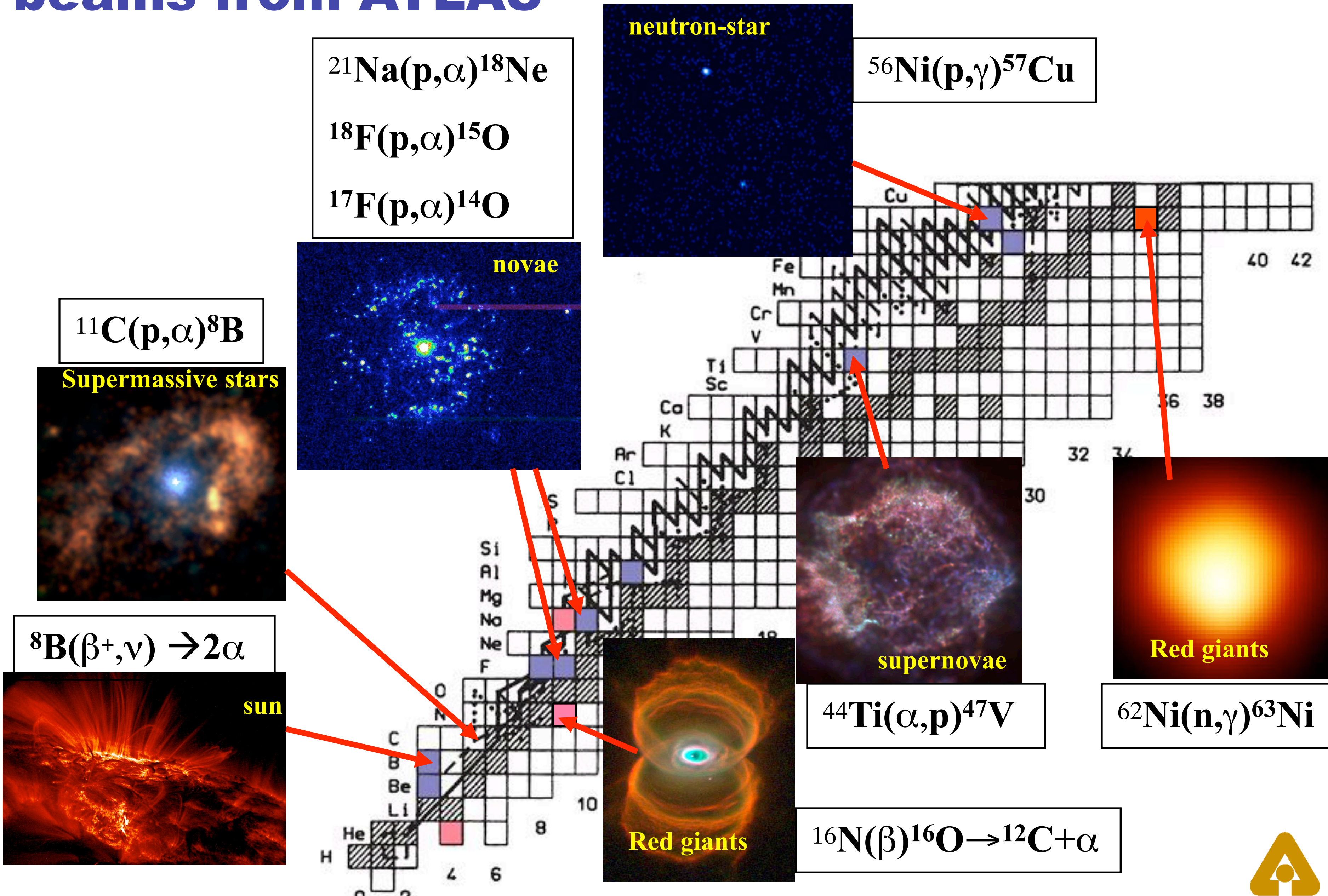
Next step: next-generation detector after Gammasphere - Greta - array of γ-ray *tracking* detectors

Nuclear astrophysics - how does nature make elements above H and He?

- Do experiments to study nuclei along various "pathways" to the heavy elements
- Have used accelerators of stable isotopes in the past
- Can reach more nuclei along these pathways using radioactive beam accelerators
- Currently Holifield at ORNL, NSCL at MSU, Atlas at ANL
- Next is CARIBU at Argonne and FRIB: Facility for Rare Isotope Beams



Nuclear astrophysics studies with radioactive beams from ATLAS



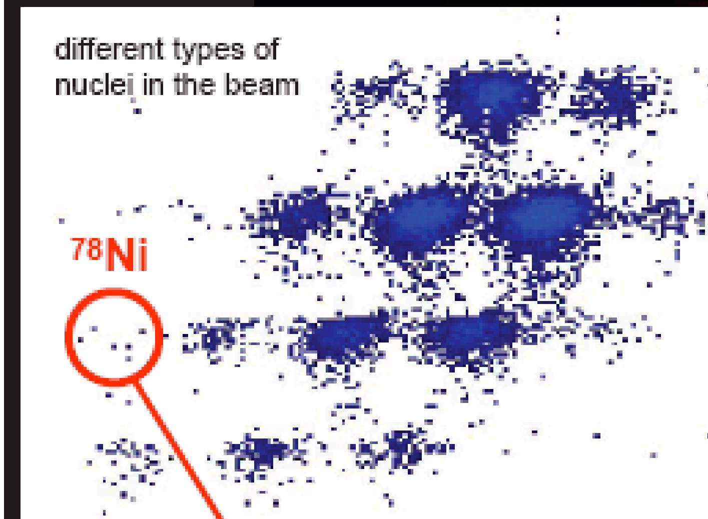
Doubly Magic ^{78}Ni Accelerates Heavy Element Synthesis

NSCL

Poster by Andreas Stolz

rp-process occurs at $T > 10^9$ K and $\rho_{n,free} > 10^{20}$ cm^{-3}

Particle identification

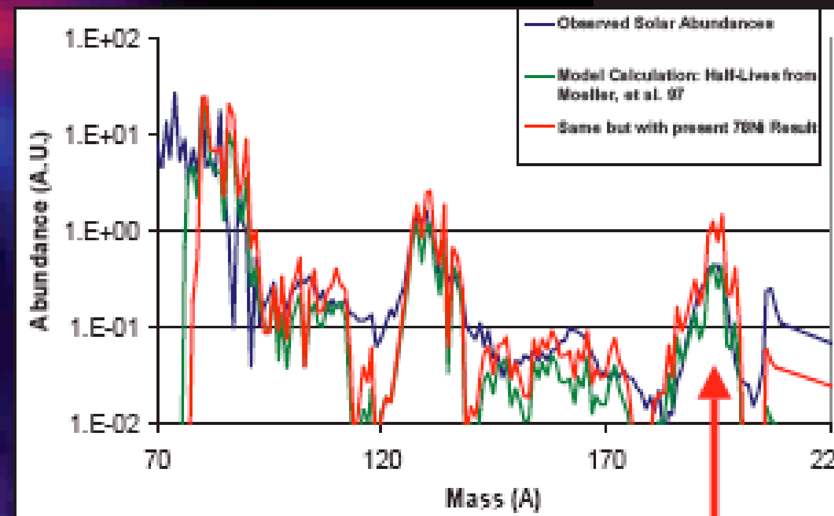


Measured half-life of ^{78}Ni with 11 events
This is the most neutron rich of the 10 possible classical doubly-magic nuclei in nature

Result: 110 $^{+100}_{-60}$ ms

P.T. Hosmer et al.
Phys. Rev. Lett. 94 (2005) 112501

Model calculation for heavy element synthesis (r-process in supernova explosion)

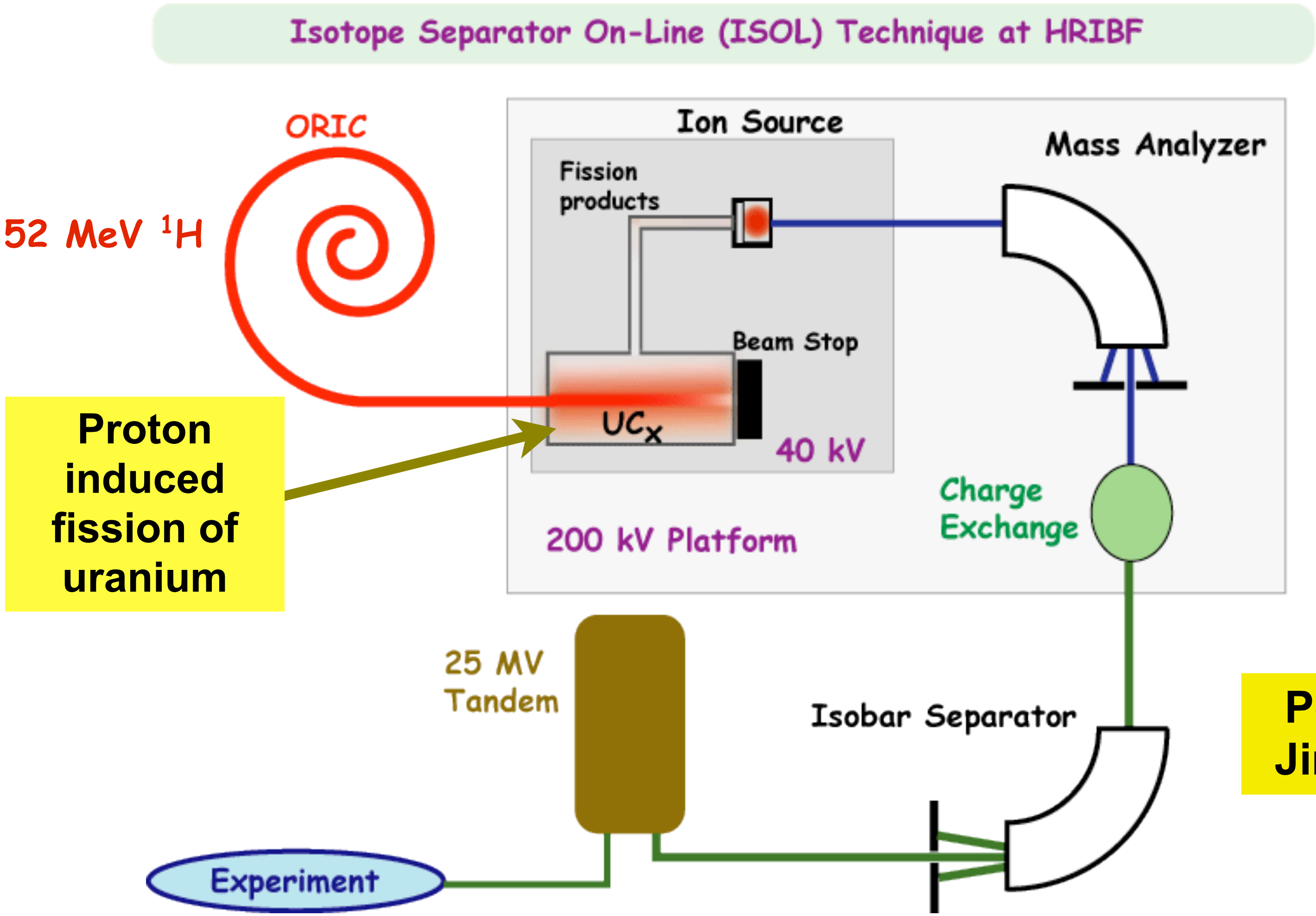


models produce excess of heavy elements with new (shorter) ^{78}Ni half-life

→Heavy element synthesis in the r-process proceeds faster than previously assumed

… one step towards a better understanding of the origin of the elements in the cosmos

Beams of radioisotopes are made and used in experiments at Holifield at Oak Ridge

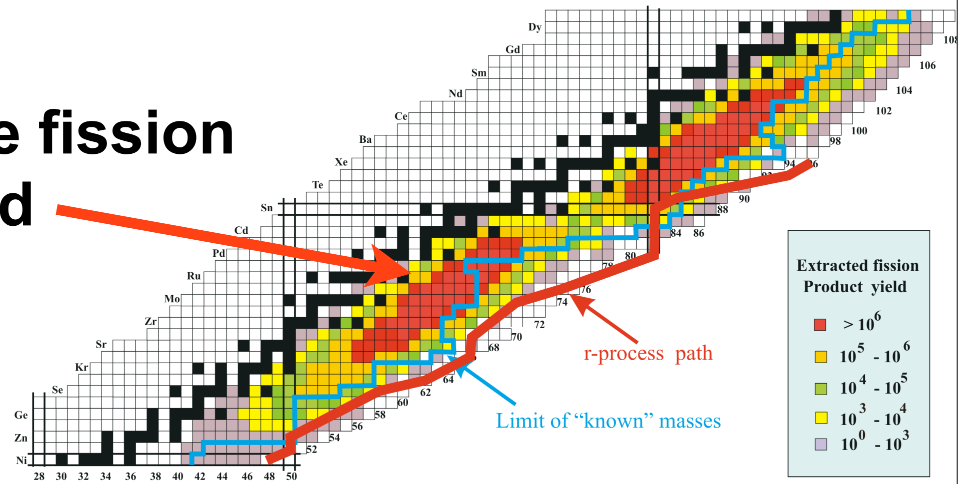


Poster by Jim Beene

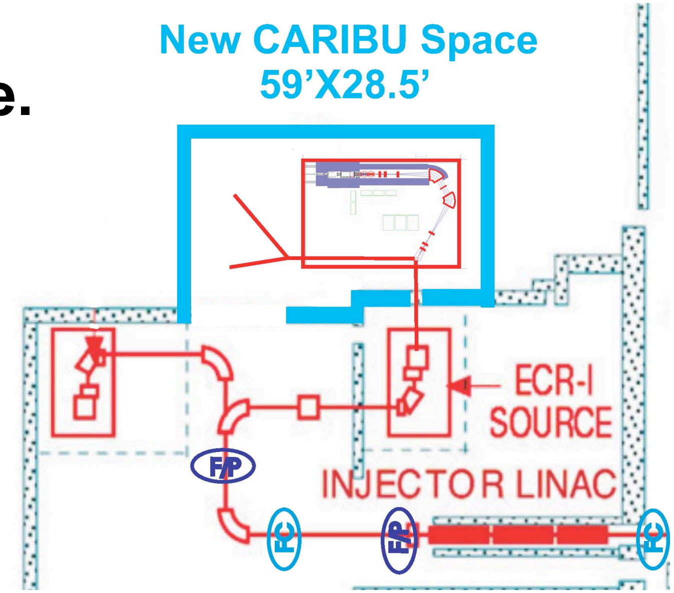
Neutron-rich radioactive ion beams (RIBs)
at energies above the Coulomb Barrier (4-10 MeV/u)

CARIBU at ANL will access more of the nuclei important for nucleosynthesis

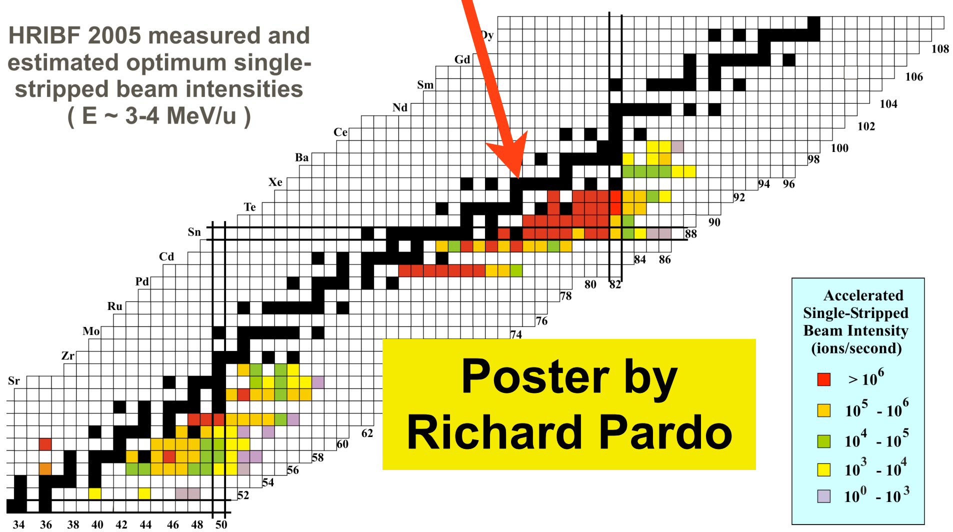
- Use a 1 Ci ^{252}Cf source to give fission fragments that are ionized and accelerated for experiments.
- This expands the accessible nuclei compared to the proton-induced fission of uranium from the Holifield facility at Oak Ridge.



New CARIBU Space
59'X28.5'



HRIBF 2005 measured and estimated optimum single-stripped beam intensities
(E ~ 3-4 MeV/u)

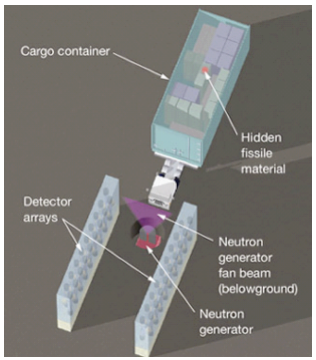


Poster by Richard Pardo

^{252}Cf is used for a variety of R&D purposes

Applied | **Basic**

Testing of neutron detectors used for various applications



n source

^{252}Cf

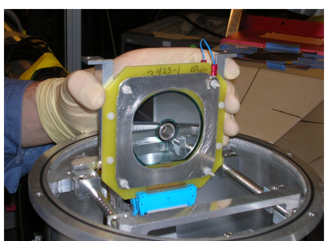
γ-ray source

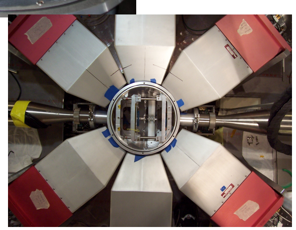
Improving basic understanding of fission and nuclear structure of n-rich fission fragments

Gammasphere

fission fragment source

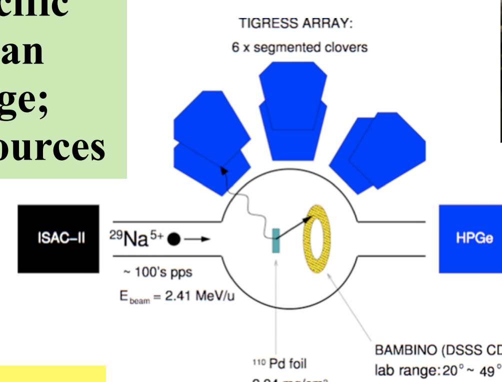
α source

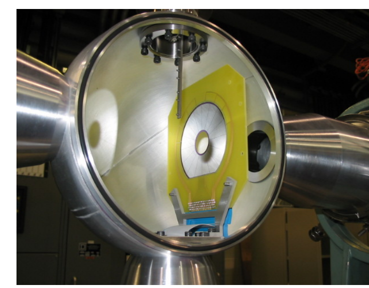




Testing of particle detectors used in surrogates experiments

High-specific activity an advantage; mass-less sources



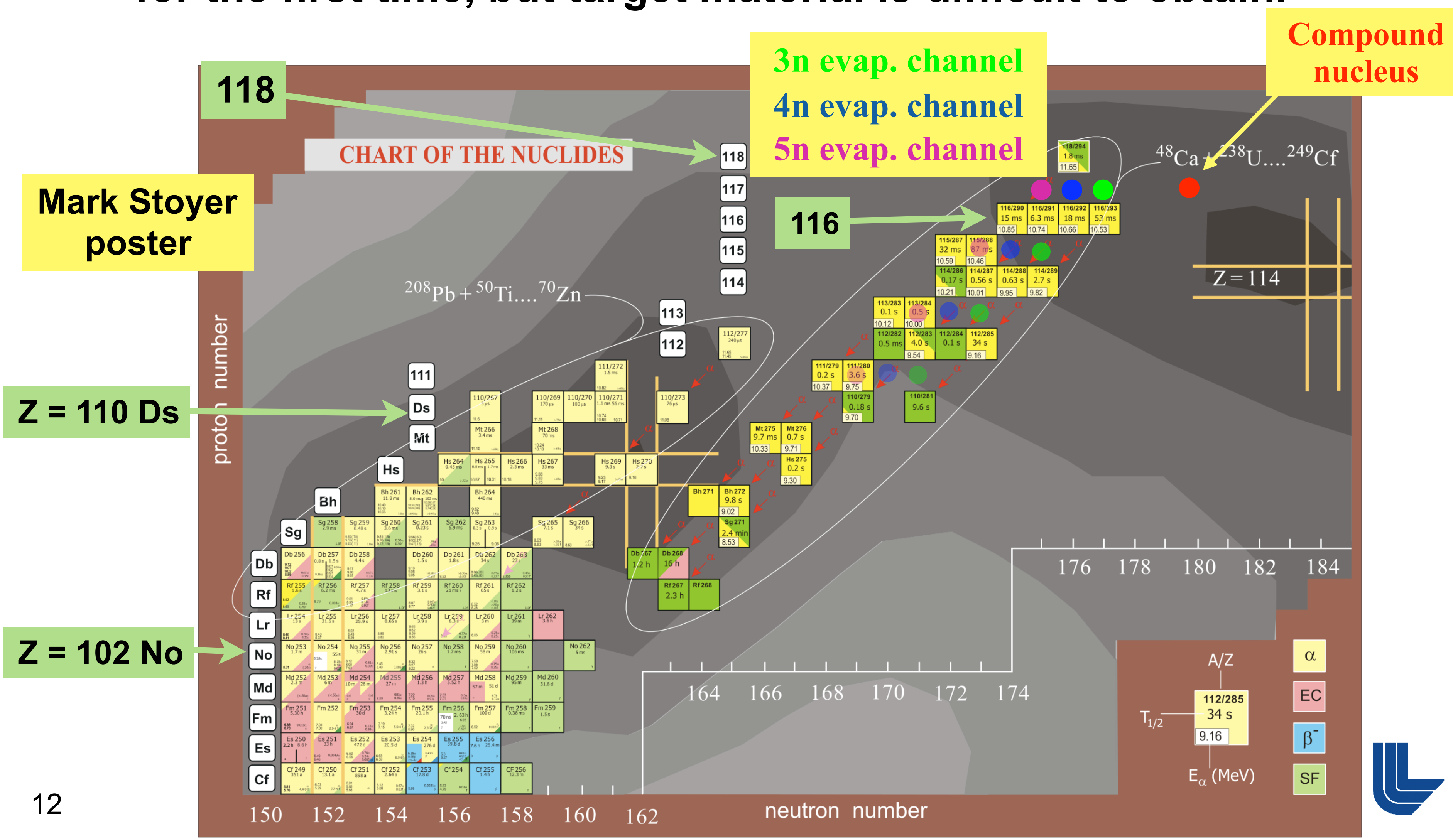


Testing of particle detectors used in RIB experiments

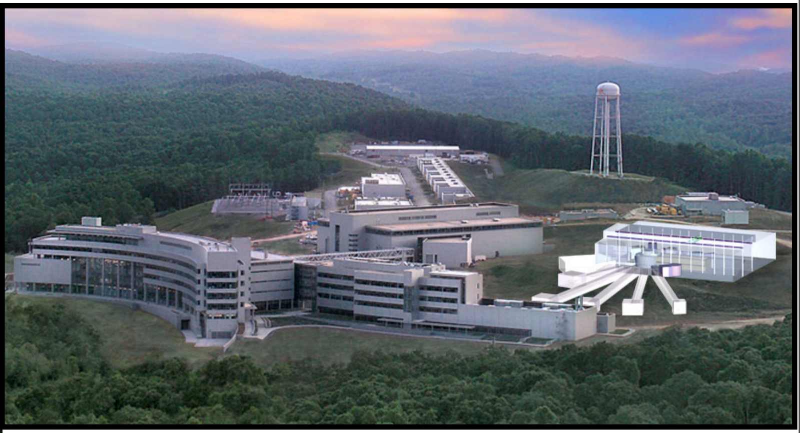
Mark Stoyer poster

Search for superheavy elements - is there an 'island of stability' around Z = 120?

The ^{48}Ca + ^{249}Bk reaction can be used to produce element 117 for the first time, but target material is difficult to obtain.



Spallation Neutron Source at Oak Ridge National Laboratory - needs heavy water



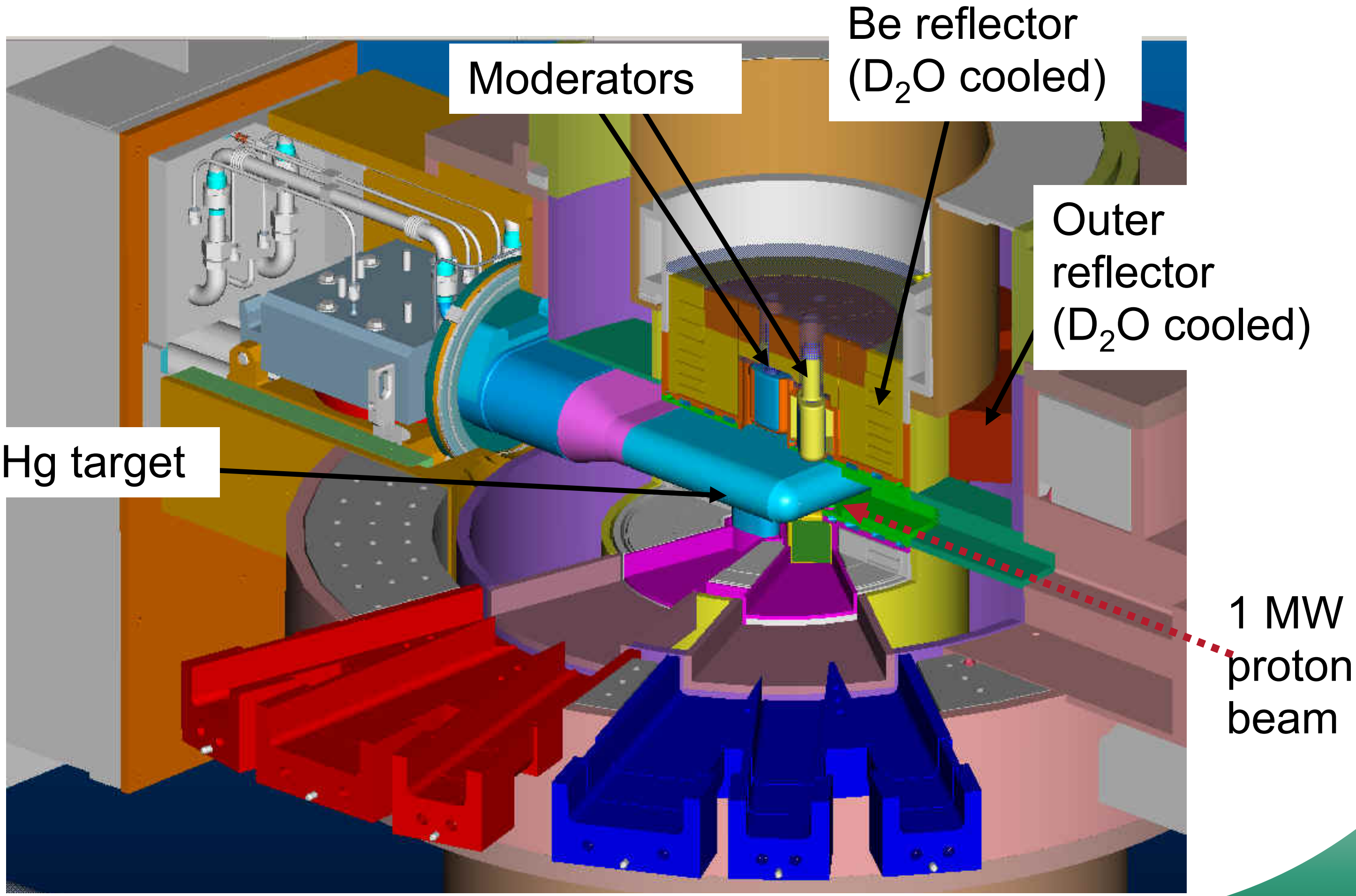
SNS site with a proposed second target station shown in white

- The SNS began operation in April 2006.
- Currently the world's highest power short pulse spallation neutron source.
- The peak neutron flux will be ~20-100 x ILL (reactor in Grenoble).
- Plans are being submitted for a second target station.

OAK RIDGE National Laboratory

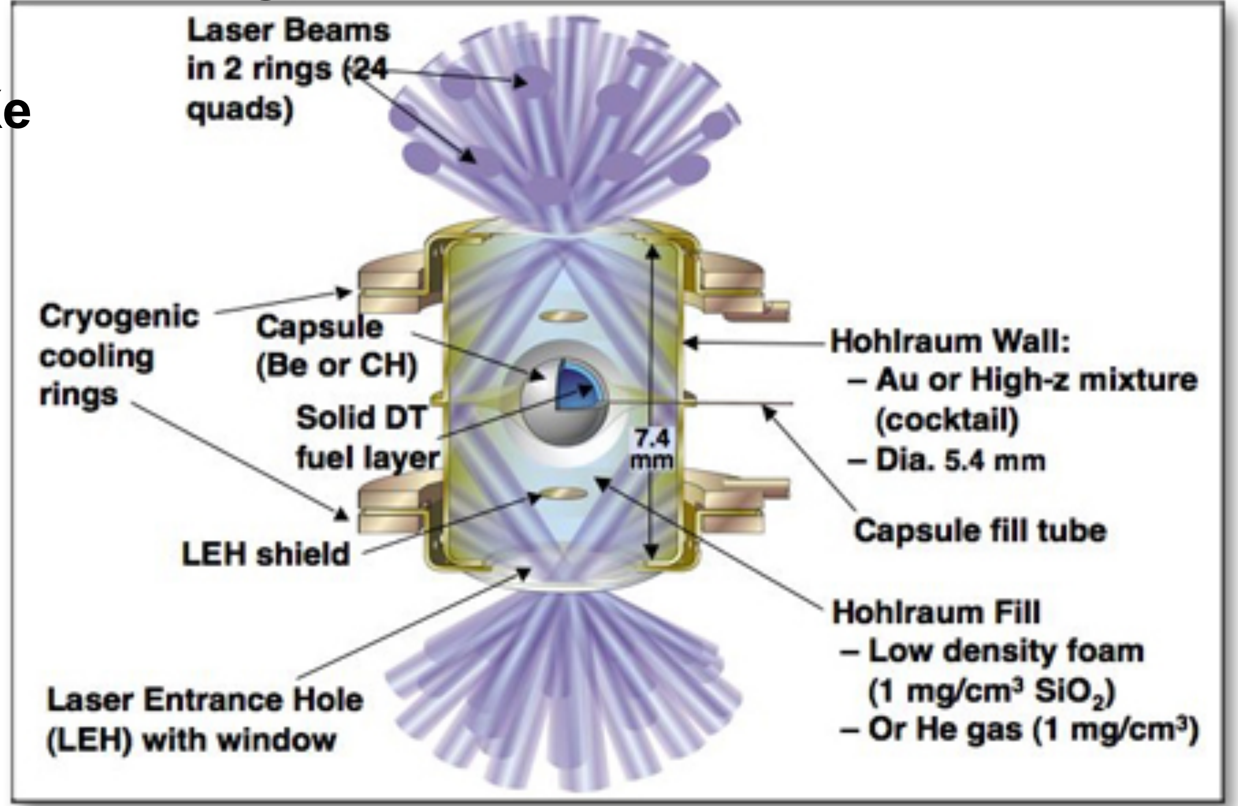
SNS target region cooling

- **The SNS began operations using light water coolant**
- **The plan is to dry the system and load heavy water - performance will increase by 15 - 20%**
- **Savannah River has provided ~5 tons of used water; need to obtain 15 tons more**



National Ignition Facility - use dopants and tracers to test capsule of frozen DT fuel

- **A laser-based inertial confinement fusion research device under construction at the Lawrence Livermore National Laboratory.**
- **NIF uses 192 powerful lasers to heat and compress a small amount of hydrogen fuel to the point where nuclear fusion takes place.**
- **Should reach the long-sought goal of "ignition", when the fusion reactions become self-sustaining.**
- **Examples of tracers are ^{22}Ne, ^{38}Ar, ^{82}Kr, ^{130}Xe**
- **Examples of dopants are ^{18}O, ^{79}B, ^{127}I, ^{126}Xe, ^{65}Cu, ^{48}Ti, ^{76}Ge**

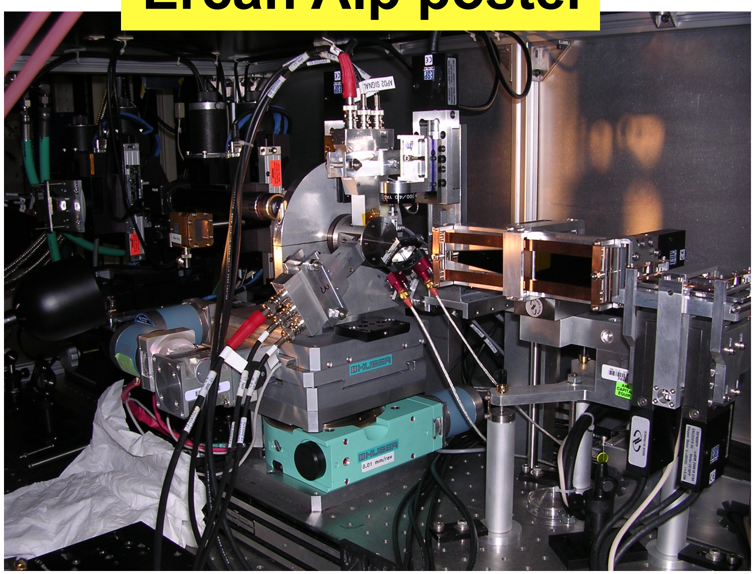


Mark Stoyer poster

Mössbauer spectroscopy using stable isotopes is used for many applications

- **Mössbauer effect has been observed using 119 isotopes**
- **64% of publications since 1958 involve ^{57}Fe**
- **Nuclear Resonant Scattering beam line at the Advanced Photon Source at Argonne is used for geophysical investigations of deep-earth minerals using enriched isotopes (e.g., ^{57}Fe) as probes**

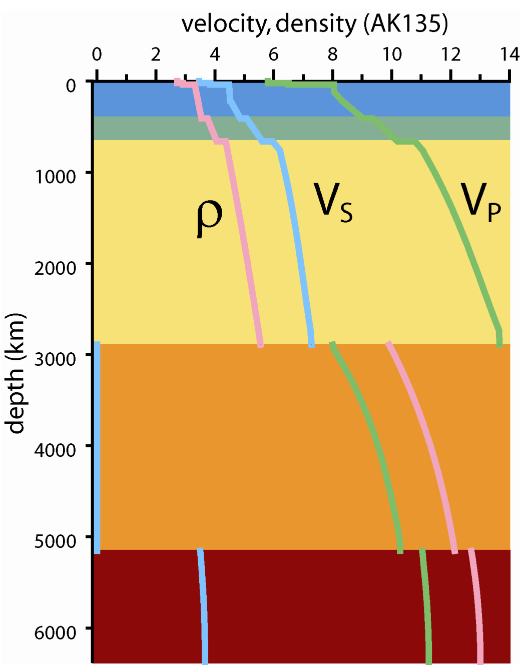
Ercan Alp poster



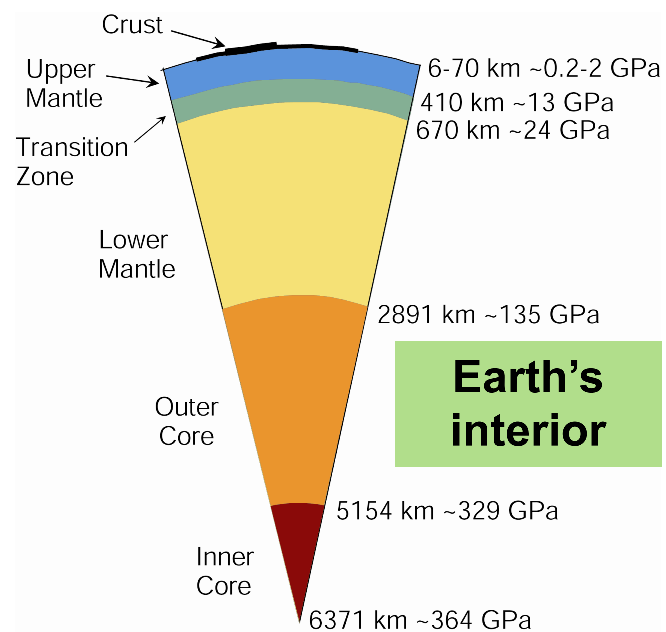
Investigate deep earth minerals using Mössbauer on ^{57}Fe at the APS

Jennifer Jackson poster

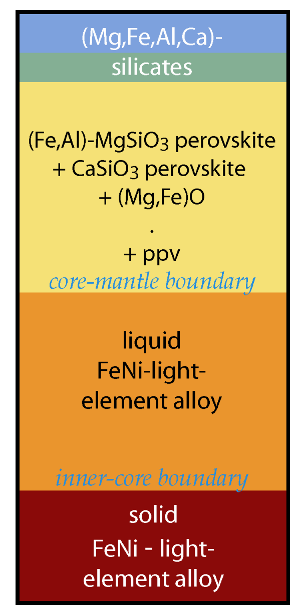
- **Use diamond anvil cell for megabar pressures**
- **Measure vibrational chemical properties of deep Earth minerals under relevant deep Earth pressures & temperatures, compare results with seismic observations**
- **High-pressure elasticity measurements on $(Mg_{0.75}Fe_{0.25})O$ show anomalous elasticity around the electronic spin-pairing crossover**



Seismic Model



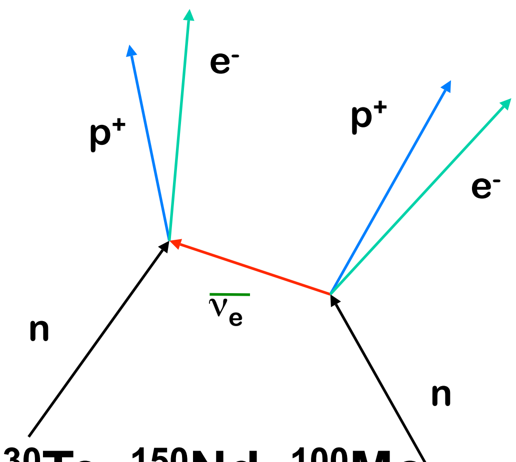
Stratified Layers



Minerals

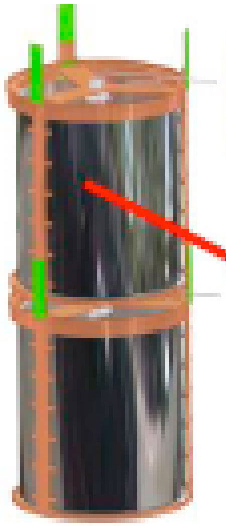
Double-beta decay experiments proposed by the Majorana Collaboration

- Search for evidence of *neutrino-less* ββ decay of ^{76}Ge to ^{76}Se
- Sensitive to neutrino mass as low as expected from recent oscillation data: $\langle m_{eff} \rangle$ = {0.02 - 0.07} eV

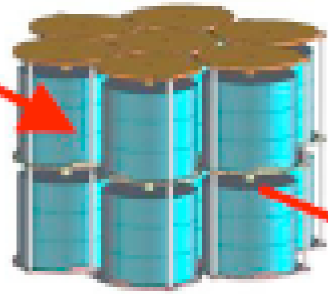


- Will also produce data on:
  - Dark matter detection
  - Search for solar axions
  - Supernova neutrinos
- Need:
  - 100 - 1000 kg of possible cases: ^{76}Ge, ^{136}Xe, ^{130}Te, ^{150}Nd, ^{100}Mo
  - Deep underground location for experiment to avoid cosmic rays
  - Ultra-low background counting technology
  - 30 kg of enriched ^{76}Ge soon to perform a "near background free" search for *neutrino-less* double-beta decay as an R&D program to prove that the full experiment is feasible
  - 1250 kg of ^{76}Ge in three years if funding for a 1-tonne experiment is approved

Experiment to be located in DUSEL

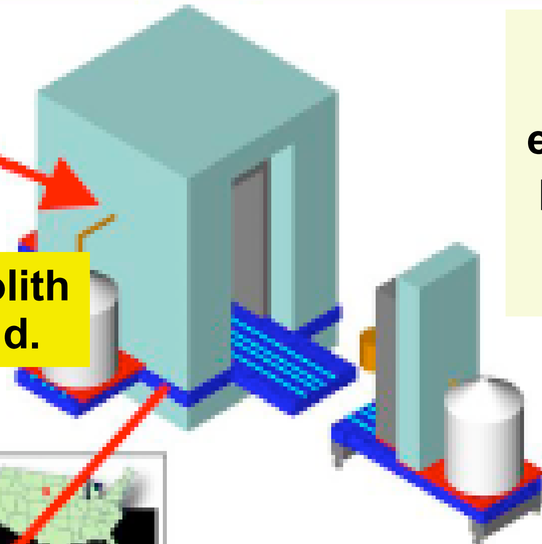


Each HPGe detector will have a 1 kg mass and may be segmented.



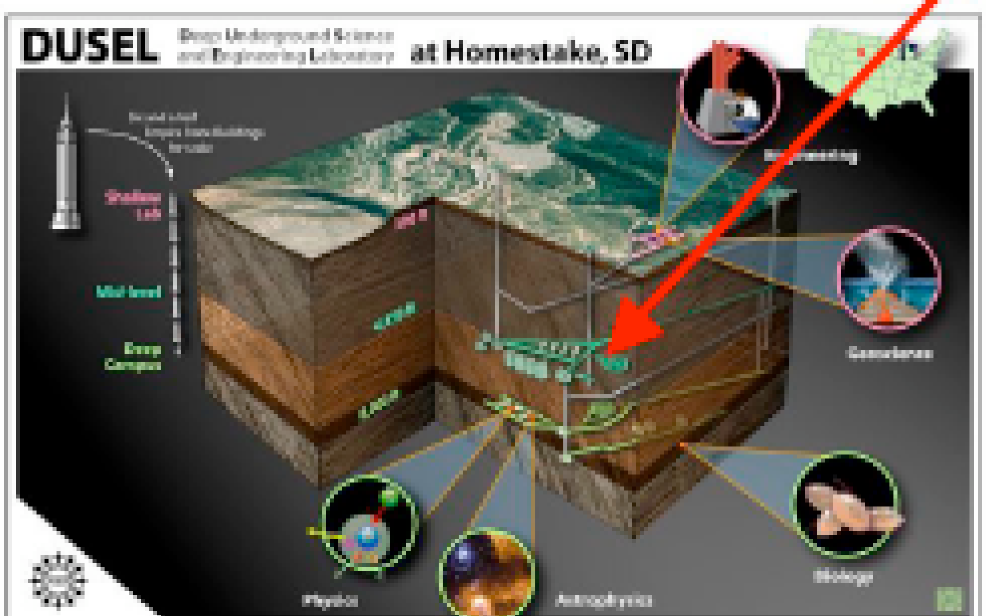
A number of detectors will be collected into a module sharing a cryostat.

Ge must be isotopically enriched, chemically purified, grown into crystals, and made into detectors.



Two of these modules form a monolith interfaced to a movable lead shield.

Richard Kouzes poster



The experiment will be placed underground in the Deep Underground Science and Engineering Laboratory (DUSEL) at the Homestake Mine in SD.

The MAJORANA Collaboration

Duke University & Triangle Universities Nuclear Laboratory, Durham, North Carolina
James Esterline, Mary Kidd, Werner Tornow

Institute for Theoretical and Experimental Physics, Moscow, Russia
Alexander Barabash, Sergey Konovalov, Igor Vanushin, Vladimir Yumatov

Joint Institute for Nuclear Research, Dubna, Russia
Viktor Brudanin, Slava Egorov, K. Gusey, S. Katulina, Oleg Kochetov, M. Shirchenko, Yu. Shitov, V. Timkin, T. Vvlov, E. Yakushev, Yu. Yurkowski

Lawrence Berkeley National Laboratory, Berkeley, California and the University of California - Berkeley
Yuen-Dat Chan, Mario Cromaz, Jason Detwiler, Brian Fujikawa, Donna Hurley, Kevin Lesko, Paul Luke, Akbar Mokhtarani, Alan Poon, Gersende Prior, Craig Tull

Lawrence Livermore National Laboratory, Livermore, California
Dave Campbell, Kai Vetter

Los Alamos National Laboratory, Los Alamos, New Mexico
Steven Elliott, Gerry Garvey, Victor M. Gehman, Vincente Guiseppe, Andrew Hime, Bill Louis, Geoffrey Mills, Kieth Rielage, Larry Rodriguez, Richard Schirato, Laura Stonehill, Richard Van de Water, Hywel White, Jan Wouters

North Carolina State University, Raleigh & Triangle Universities Nuclear Laboratory, Durham, North Carolina
Henning Back, Lance Leviner, Albert Young

Oak Ridge National Laboratory, Oak Ridge, Tennessee
Jim Beene, Fred Bertrand, David Radford, Krzysztof Rykaczewski, Chang-Hong Yu

Osaka University, Osaka, Japan
Hiroyasu Ejiri, Ryuta Hazama, Masaharu Nomachi, Shima Tatsuji

Pacific Northwest National Laboratory, Richland, Washington
Craig Aalseth, James Ely, Tom Farmer, Jim Fast, Eric Hoppe, Brian Hyronimus, David Jordan, Jeremy Kephart, Richard T. Kouzes, Harry Miley, John Orrell, Jim Reeves, Robert Runkle, Bob Schenter, John Smart, Bob Thompson, Ray Warner, Glen Warren

Queen's University, Kingston, Ontario, Canada
Fraser Duncan, Aksel Hallin, Art McDonald

University of Alberta, Edmonton, Alberta, Canada
Fraser Duncan, Aksel Hallin, Art McDonald

University of Chicago, Chicago, Illinois
Phil Barbeau, Juan Collar, Keith Crum, Smritri Mishra, Brian Odom, Nathan Riley

University of North Carolina - Chapel Hill & Triangle Universities Nuclear Laboratory, Durham, North Carolina
Padraic Finnerty, Reyco Henning, Eliza Osenbaugh-Stewart

University of South Carolina, Columbia, South Carolina
Frank Avignone, Richard Creswick, Horatio A. Farach, Todd Hossbach

University of South Dakolta, Vermillion, South Dakota
Tina Keller, Dongming Mei, Zhongbao YIN

University of Tennessee, Knoxville, Tennessee
William Bugg, Tom Handler, Yuri Efremenko, Brandon White

University of Washington, Seattle, Washington
John Amsbaugh, Tom Burritt, Peter J. Doe, Jessica Dunmore, Alejandro Garcia, Mark Howe, Rob Johnson, Michael Marino, R. G. Hamish Robertson, Alexis Schubert, Brent VanDevender, John F. Wilkerson

Note: Red text indicates students

Uses of stable isotopes in human nutrition research - Department of Agriculture

- **Obesity Prevention** – ^{18}O and ^{2}H labeled water to estimate energy expenditure in humans to understand food and physical activity energy balance
- **Bioactive Food Components** – ^{13}C labeled organic compounds in plant foods for human feeding trials to measure absorption and bioavailability; example: labeled anthocyanins in strawberries
- **Human metabolism studies** – tracing compounds of interest via the ICP-MS analysis of enriched stable isotopes to understand nutrient metabolism and utilization; examples: $^{57,58}Fe$, $^{67,70}Zn$, ^{13}C, ^{15}N, $^{42,47}Ca$, $^{25,26}Mg$

USDA

Stable isotopes used in NIH nutrition research - mineral absorption and distribution in body

- **Mineral nutrition is important for children diets:**
  - **meets children's growth and developmental needs**
  - **may limit disease processes and prevent future diseases**
- **Need to provide a rational basis for establishing new dietary guidelines for children**
- **Children are a particularly challenging group on which to perform nutrition research**
- **Stable isotope-based research offers a unique way to obtain data needed to establish dietary guidelines**
- **Use enriched stable isotopes of Ca, Fe, Zn, Mg, Cu**

Steve Abrams, Baylor College of Medicine
Alfred Yergey, NIH

Texas Children's Hospital

National Institutes of Health

Benefits to using stable isotopes to assess mineral requirements in children

- Are safe for all populations
- Can do accurate measurement of fractional absorption in a population where long-term dietary regulation is impossible
- Assess absorption without fecal collections
- Provide physiological data (kinetics) in addition to absorption/excretion data

Key research questions:

- How much iron is absorbed from human milk? What are the effects of lactoferrin and solid foods on iron absorption?
- What are the consequences of Ca-Fe interaction on iron supplementation programs? Is there long-term adaptation of iron absorption to higher calcium-containing diets?

NIST Standard Reference Materials program uses many stable isotopes

- **Enriched stable isotopes are used as spikes in *isotope dilution mass spectrometry* for concentration determinations in the SRM certification program.**
- **ICP-MS (inductively coupled plasma mass spectrometry) is highly sensitive and capable of determining a range of metals and several non-metals at concentrations below one part in 10^{12}.**
- **One use of ICP-MS is in the medical and forensic field - physician orders a metal assay due to suspicion of heavy metal poisoning or metabolic concerns.**
- **Expanding future needs will relate to benchmarking environmental, energy, security (e.g. point-of-origin), and medical isotopic measurements.**

NIST National Institute of Standards and Technology

Therapeutic radionuclides used for research in nuclear medicine

Lutetium-177	Beta emitter	6.7-d half-life	Reactor
Astatine-211	Alpha emitter	7.2-h half-life	Accelerator
Yttrium-90	Beta emitter	64-h half-life	Reactor
Rhenium-186	Beta emitter	3.7-d half-life	Reactor
Rhenium-188	Beta emitter	17-h half-life	Reactor
Holmium-166	Beta emitter	27-h half-life	Reactor
Iodine-131	Beta emitter	8.0-d half-life	Reactor
Samarium-153	Beta emitter	46-h half-life	Reactor
Bromine-77	Beta emitter	57-h half-life	Accelerator
Copper-67	Beta emitter	62-h half-life	Accelerator
Actinium-225	Alpha emitter	10.0-d half-life	Accelerator
Strontium-89	Beta emitter	50.5-d half-life	Reactor

Michael Welch will cover some of these in his talk