Comments on the Importance of Access/Availability of a Broad Suite of Isotopes to Basic Research

The 3rd Isotope Federal Supply and Demand Workshop
November 3, 2014

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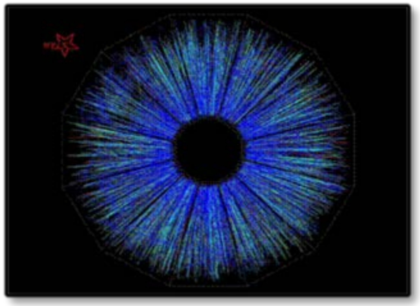
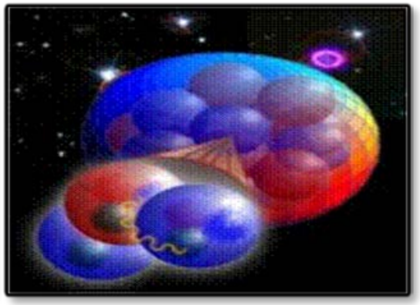
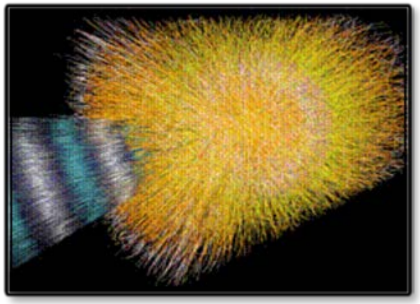
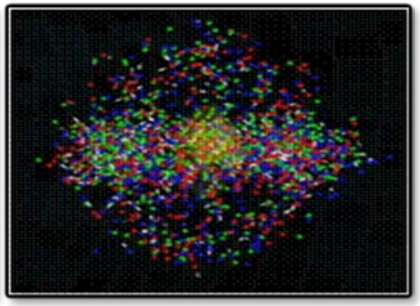
DOE Office of Science

Disclaimer

In preparing this talk, I have not limited the topics to isotopes that are currently being produced or researched by the DOE isotope program.

Why is that fair?

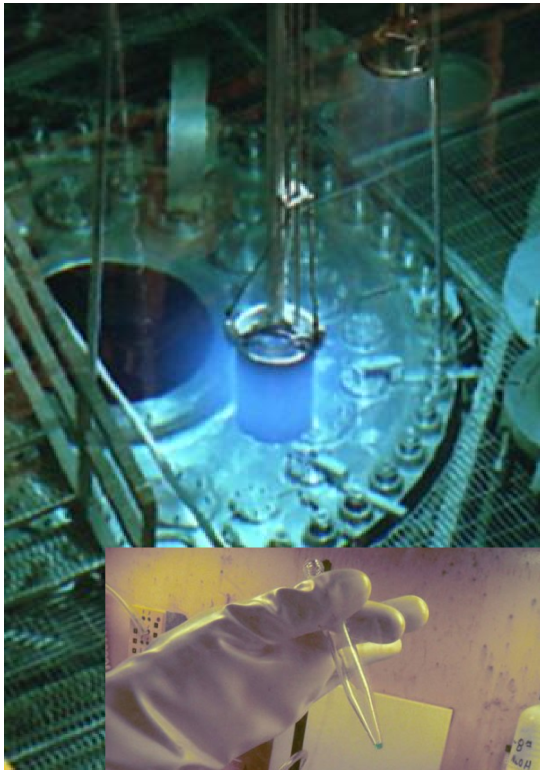
Even for isotopes produced commercially (not by DOE) today, knowledge of their properties or relevance for various research projects has come in the past, or is coming now from the type of research the DOE isotope program is supporting

Some isotopes are only available today because of stocks produced in the past for which the DOE Isotope program is now the steward

It lets me show you some really cool examples of the importance of isotopes to basic research

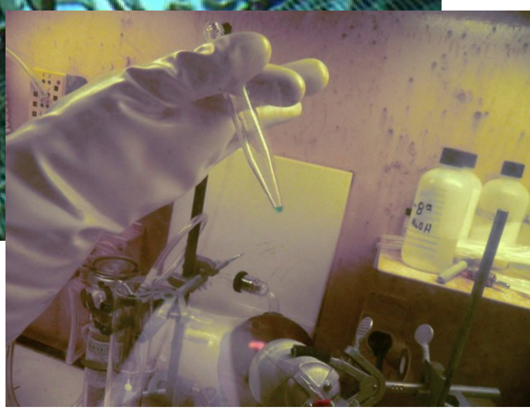
First Example: The Discovery of New Elements (e.g.117)

High Flux Isotope Reactor at ORNL



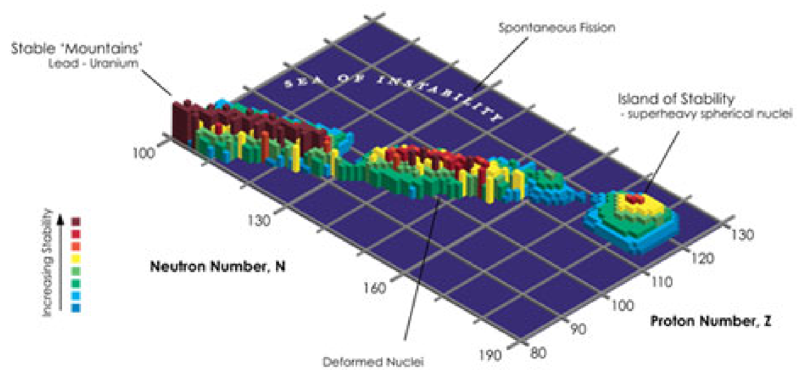
The New York Times

Scientists Discover Heavy New Element
By JAMES GLANZ
Published: April 6, 2010
A team of Russian and American scientists has discovered a new element that has long stood as a missing link among the heaviest bits of atomic matter ever produced. The element, still nameless, appears to point the way toward a brew of still more massive elements with chemical properties no one can predict.



It took 250 days to make enough Berkelium, shown here, to synthesize element 117

By bombarding it with ^{40}Ca (also supplied by the U.S.)



Discovery of Super Heavy Element 117

Selenium Speciation in the Eastern Tropical and Subtropical South Pacific Ocean

Yuzuru NAKAGUCHI[a,b], Yasunobu MITSUHASHI[c], Ken-ich KITAHATA[c], Akinori FUJITA[c], Ayako SUMIYOSHI[a], and Yasuko KAWAI[a]

al., 1988). Baines and Fisher have investigated the interspecific differences in the bioconcentrations of selenite by phytoplankton. Statistically significant differences in selenium concentrations were recognized among the algal divisons. The content of selenium in algal may vary in some species, depending on the phase of growth (Baines and Fisher, 2001). These investigation results suggest that selenium requirements and assimilation for marine phytoplankton differ among plankton species. The information obtained regarding plankton species at the sampling point will need to be considered in light of the regeneration process of selenium via microorganism action.

Concentration in nano-Moles

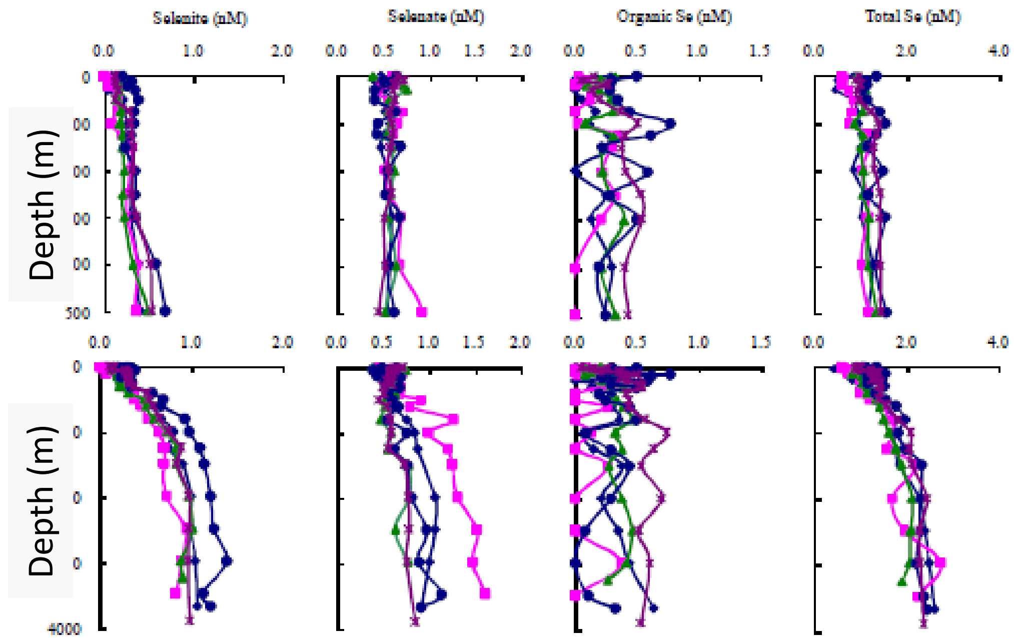


Fig. 3 Vertical profiles of selenite, selenate and organic selenium at HY03(◆), HY04(■) HY06(▲), HY08(●) and HY09(×).

A big uncertainty: uptake and processing of Se by phytoplankton of various types

Addressing Uncertainty in the Selenium Abundance Using Isotopes

Assimilation of selenium from phytoplankton by three benthic invertebrates: effect of phytoplankton species

SCHLEKAT Christian E. [1] ; LEE Byeong-Gweon [2] ; LUOMA Samuel N. [1] ; [1] US Geological Survey, Water Resources Division, 345 Middlefield Road, MS 465, Menlo Park, California 94025, ETATS-UNIS, [2] Chonnam National University, Department of Oceanography, Kwang Ju, COREE, REPUBLIQUE DE

Abstract

Phytoplankton are an important source of selenium (Se) for aquatic invertebrates, which accumulate Se primarily through dietary ingestion. The extent to which Se bioavailability varies among different phytoplankton species could help explain different bioaccumulation patterns observed for invertebrates in nature. We measured the efficiency with which 3 benthic invertebrates assimilated ^{75}Se from 5 phytoplankton species using standard pulse-chase techniques…. The range of Se assimilation efficiency (AE) by L. plumulosus (32.1 ± 1.8 to 69.5 ± 7.1 %) was the lowest of the 3 organisms. No relationship was observed between the proportion of Se in algal cell cytoplasm and Se AE by L. plumulosus, which is consistent with findings for assimilation of other trace elements by this organism. Se AE by M. balthica (range: 58.0 ± 3.2 to 92.3 ± 6.0%) varied according to the proportion of cytoplasmic Se in algal cells ($p < 0.0001$, $r^2 = 0.868$). P. amurensis assimilated between 78.3 ± 2.0 and 88.9 ± 3.6 % of Se from algal cells, and the relationship between cytoplasmic Se and Se AE was described by the following equation: Se AE = 69.2 + 0.22 x (% cytoplasmic Se) ($p = 0.003$, $r^2 = 0.405$). This relationship suggests that P. amurensis assimilated non-cytoplasmic Se from phytoplankton, perhaps through utilization of the glandular digestive pathway. Consistently high Se assimilation from algae by P. amurensis may contribute to elevated Se concentrations observed for this organism.

Similarly…Si Isotopes Are Essential to Ocean Research

Letters to Nature

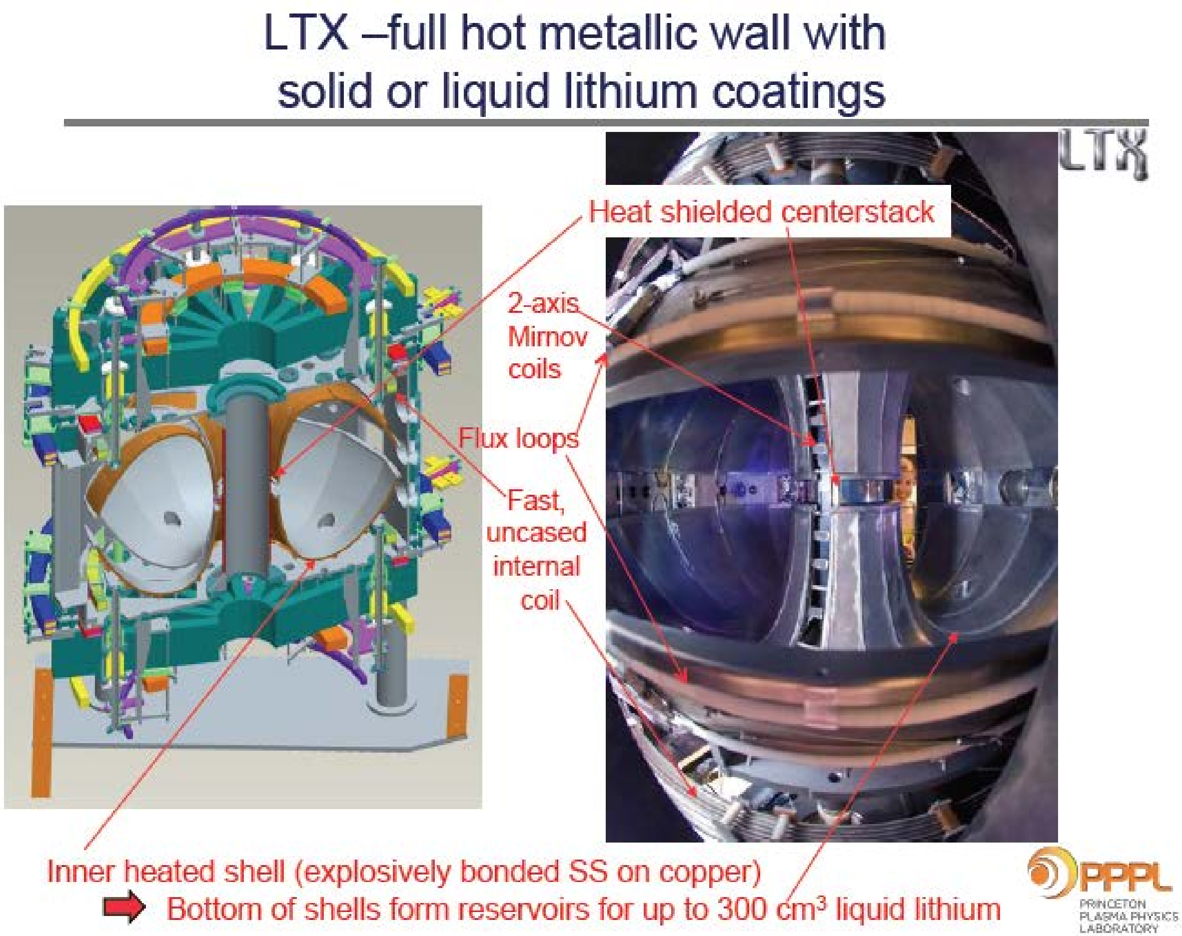
Nature **395**, 680-683 (15 October 1998)

Silicon-isotope composition of diatoms as an indicator of past oceanic change

C. L. De La Rocha[1,2,3], M. A. Brzezinski[1,2], M. J. DeNiro[1,4] & A. Shemesh[5]

Silicon is essential for the growth of diatoms, a group of phytoplankton with opal (amorphous hydrated silica) shells. Diatoms largely control the cycling of silicon in the ocean[1] and, conversely, diatom silica production rates can be limited by the availability of silicic acid[2]. Diatoms are biogeochemically important in that they account for an estimated 75% of the primary production occurring in coastal and nutrient-replete waters[1], rising to more than 90% during ice-edge blooms such as occur in the Ross Sea, off Antarctica[3]. There are few means by which to reconstruct the history of diatom productivity and marine silicon cycling, and thus to explore the potential contribution of diatoms to past oceanic biogeochemistry or climate. Indices based on the accumulation of sedimentary opal are often biased by the winnowing and focusing of sediments and by opal dissolution[4, 5, 6, 7]. Normalization of opal accumulation records using particle-reactive natural radionuclides may correct for sediment redistribution artefacts and the dissolution of opal within sediments[6,8], but not for opal dissolution before it arrives at the sea floor….Here we exploit the potential that variations in the ratio of ^{30}Si to ^{28}Si in sedimentary opal may provide information on past silicon cycling that is unbiased by opal dissolution. Our silicon stable-isotope measurements suggest that the percentage utilization of silicic acid by diatoms in the Southern Ocean during the last glacial period was strongly diminished relative to the present interglacial.

Isotopes and Fusion Research?

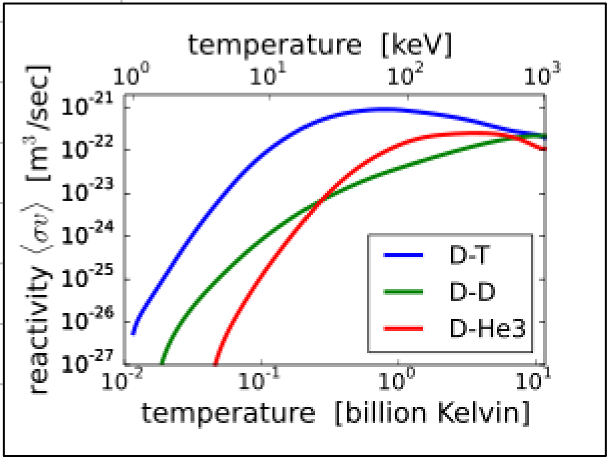


For magnetic fusion energy to fuel future power plants, scientists must find ways to control the interactions that take place between the volatile edge of the plasma and the walls that surround it in fusion facilities. Such interactions can profoundly affect conditions at the superhot core of the plasma in ways that include kicking up impurities that cool down the core and halt fusion reactions

Researchers have improved plasma performance by applying lithium coatings to the walls of fusion facilities. But a complete understanding of the mechanism behind this improvement remains elusive. Among the puzzles is how temperature affects the ability of lithium to absorb and retain the deuterium particles that stray from the fuel that creates fusion reactions.

More to the Heart of the (Fusion) Matter, Isotopes are Important for the Fuel

Comparison of neutronicity of reactions[7][8][9][10][11]				
Reactants		Products	*Q*	n/MeV
First-generation fusion fuels				
$^{2}_{1}H$ + $^{2}_{1}H$ (D-D)	→	$^{3}_{2}He$ + $^{1}_{0}n$	3.268 MeV	0.306
$^{2}_{1}H$ + $^{2}_{1}H$ (D-D)	→	$^{3}_{1}H$ + $^{1}_{1}p$	4.032 MeV	0
$^{2}_{1}H$ + $^{3}_{1}H$ (D-T)	→	$^{4}_{2}He$ + $^{1}_{0}n$	17.571 MeV	0.057
Second-generation fusion fuel				
$^{2}_{1}H$ + $^{3}_{2}He$ (D-^{3}He)	→	$^{4}_{2}He$ + $^{1}_{1}p$	18.354 MeV	0
Third-generation fusion fuels				
$^{3}_{2}He$ + $^{3}_{2}He$	→	$^{4}_{2}He$+ 2$^{1}_{1}p$	12.86 MeV	0
$^{11}_{5}B$ + $^{1}_{1}p$	→	3 $^{4}_{2}He$	8.68 MeV	0
Net result of D burning (sum of first 4 rows)				
6D	→	2(^{4}He + n + p)	43.225 MeV	0.046
Current nuclear fuel				
^{235}U + n	→	2 FP+ 2.5n	~200 MeV	0.001



Fusion Energy Poses Some Very Significant Challenges

^{3}He can be used in fusion reactions by either of the reactions $^{2}D + {}^{3}He \rightarrow {}^{4}He + {}^{1}p$ + 18.3 MeV, or $^{3}He + {}^{3}He \rightarrow {}^{4}He + 2\,{}^{1}p$+ 12.86 MeV

The conventional deuterium + tritium ("D-T") fusion process produces energetic neutrons which render reactor components radioactive with activation products. The appeal of helium-3 fusion stems from the aneutronic nature of its reaction products. Helium-3 itself is non-radioactive. The lone high-energy by-product, the proton, can be contained using electric and magnetic fields. The momentum energy of this proton (created in the fusion process) will interact with the containing electromagnetic field, resulting in direct net electricity generation.[12]

…$^{3}_{2}He + {}^{3}_{2}He$ fusion has been demonstrated in the laboratory and is thus theoretically feasible and would have immense advantages, but commercial viability is many years in the future.

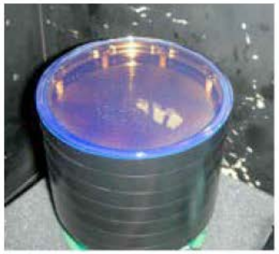
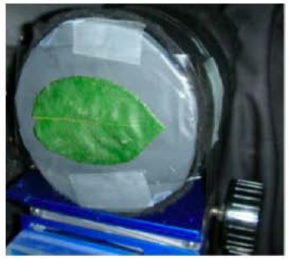
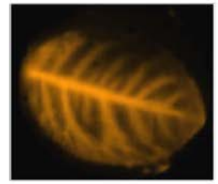
The amounts of helium-3 needed as a replacement for conventional fuels are substantial by comparison to amounts currently available. The total amount of energy produced in the $^{2}_{1}H + {}^{3}_{2}He$ reaction is 18.4 MeV, which corresponds to some 493 megawatt-hours (4.93×10^{8} W·h) per three grams (one mole) of ^{3}He. If the total amount of energy could be converted to electrical power with 100% efficiency (a physical impossibility), it would correspond to about 30 minutes of output of a gigawatt electrical plant per mole of ^{3}He. Thus, a year's production would require 52.5 kilograms of helium-3.The amount of fuel needed for large-scale applications can also be put in terms of total consumption: electricity consumption by 107 million U.S. households in 2001 totaled 1,140 billion kW·h (1.14×10^{15} W·h). Again assuming 100% conversion efficiency, 6.7 tonnes per year of helium-3 would be required for that segment of the energy demand of the United States, 15 to 20 tonnes per year given a more realistic end-to-end conversion efficiency.

Isotopes in Bio-Research Closer to Home

Instrumentation Development for Plant Research at the Triangle Universities Nuclear Laboratory

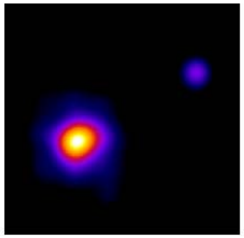
Plant physiology studies at TUNL use a variety of short-lived isotopes in radiotracing measurements. Two recently developed capabilities for this research are production of nitrogen-13 (N-13) in a water target and pulsed-loading of carbon-11 (C-11). Administering N-13 as a solution of aqueous nitrate ions allows researchers to observe plant uptake of nitrogen through the roots. The nitrogen tracer is produced through proton bombardment of a natural water target. Two main species of isotopes form during irradiation: the desired N-13 and a fluorine-18 (F-18) contaminant. A scrubber containing alumina pellets reduces the F-18 contamination by about an order of magnitude. C-11 administered as gaseous carbon dioxide allows researchers to observe plant uptake of carbon from the atmosphere. A system was constructed to deliver C-11 tagged air in bursts of adjustable width. The radioactive signatures of such pulses have sharp leading and trailing edges. This differs from the usual loading technique where the gradual exponential decay of C-11 dominates the trailing edge.

Plant Biology Specific β+ Imaging Detector Development

R3292 110mm diam. Hamamatsu PSPMT coupled to BC400 0.5mm thick plastic scintillator, 15 microns Mylar film and 25 micron Tedlar film were applied on top of the scintillating plastic. Detector ~600X more sensitive that dual planar PET.



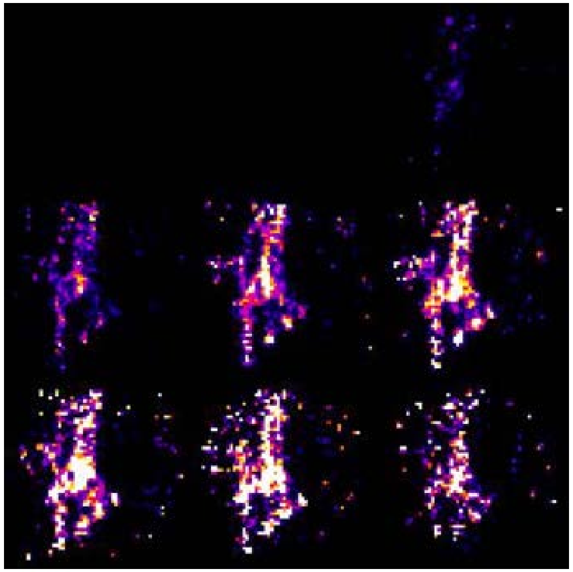


“Detector on a

H8500 Hamamatsu 5cm x 5cm PSPMT – 2 mm thick BC408 plastic scintillator Cs137 & Cd109 electron sources

PET Imaging of Carbon Dioxide Utilization in Plant

Montage of root area reconstructed images. Time bin for each image was 20 minutes. Images are decay corrected for the half-life of ^{11}C. Time bin was 20 minutes, images are decay corrected for the half-life of ^{11}C



Use of Isotopes in Materials Research

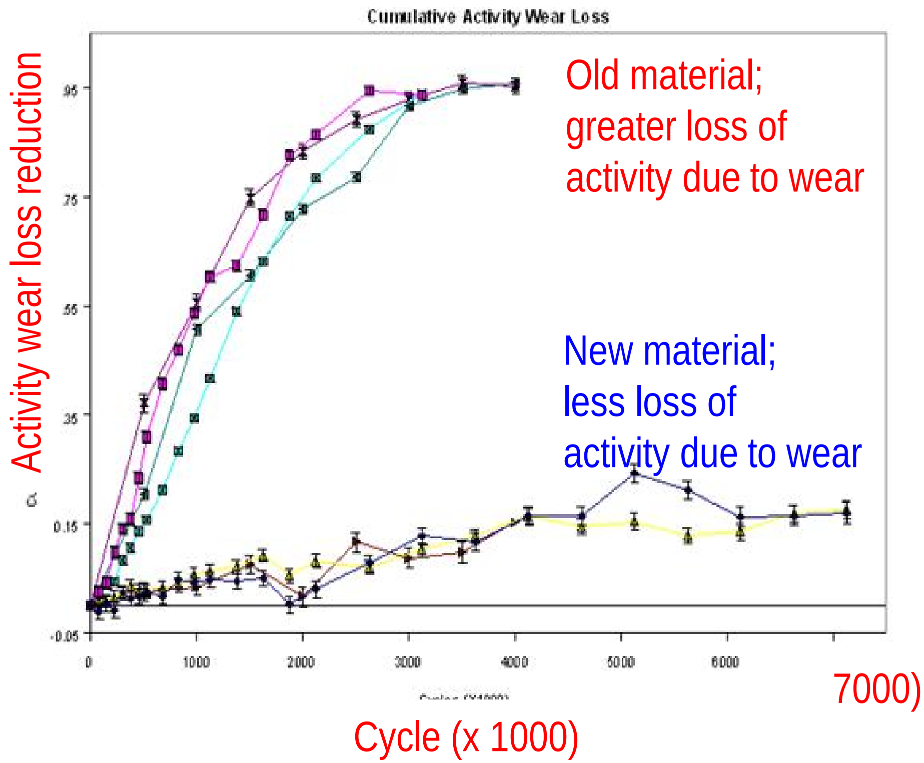
Statement of Problem: Effective means of determining wear at metal-plastic pin interface (200,000 hip-joint procedures per year)

Approach:
^{7}Be produced in Atomki (Hungary) via 7Li(p,n)7Be reaction chemically separated at Holifield Rare Isotope Beam Facility, & uniformly implanted to 9 µm in test material using setup from Colorado School of Mines to give activity plateau

Motion wear simulator from Rush University Medical Center in Chicago deployed at Argonne National Laboratory

Reduction in activity of 7Be measured as a function of simulated wear cycles using a 20% Ge detector to determine wear loss. 1,000,000 cycles possible in a week; well matched to half life of ^{7}Be

Preliminary Indication of this proof of principle test: New material approximately 13 times more resistant to wear than material used previous material



Cumulative 7Be activity wear loss versus wear cycles.

Upper group of curves: standard high density polyethylene;

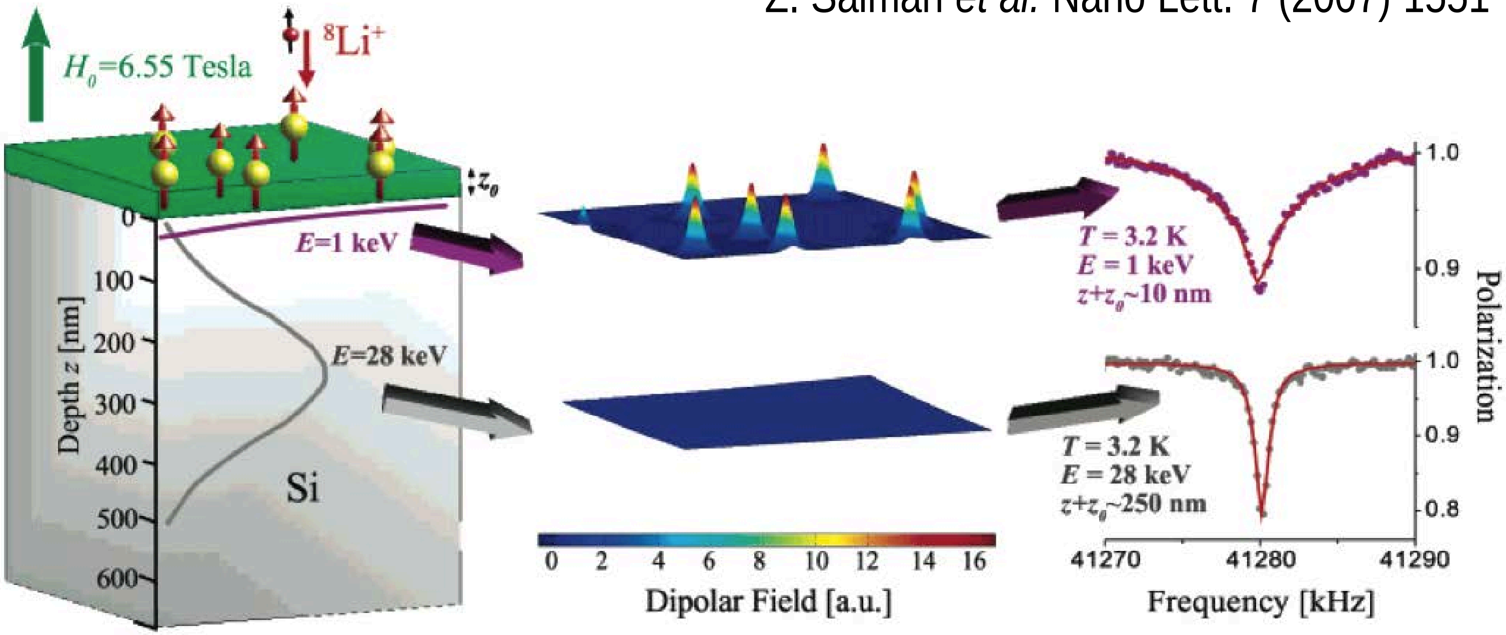
Lower group of curves: new cross-linked high density polyethylene

New material is about 13 times more resilient to wear.

^{8}Li β-NMR Resonance Studies

- Polarized ^{8}Li implanted below monolayer of Mn_{12} single molecule magnets on Si substrate to study dipolar field of SMM; potential application information storage, quantum research on single spins, quantum tunneling of magnetization
- Sensitivity 10^{13} higher than NMR
- Discovery potential of β -NMR very high in exploring depth dependent properties, interfaces, and proximity effects from 5 to 200 nm.
- Limited by availability of ^{8}Li

Z. Salman *et al.* Nano Lett. 7 (2007) 1551



An example of Isotopes in High Energy Physics

Two major recent discoveries in HEP:

The Higgs particle at CERN

The Neutrino Mixing Angle θ_{13} at Daya Bay, China

Neutrino Detection Pool at Daya Bay

Why is θ_{13} research important? A precise Measurement of θ_{13} bears on:

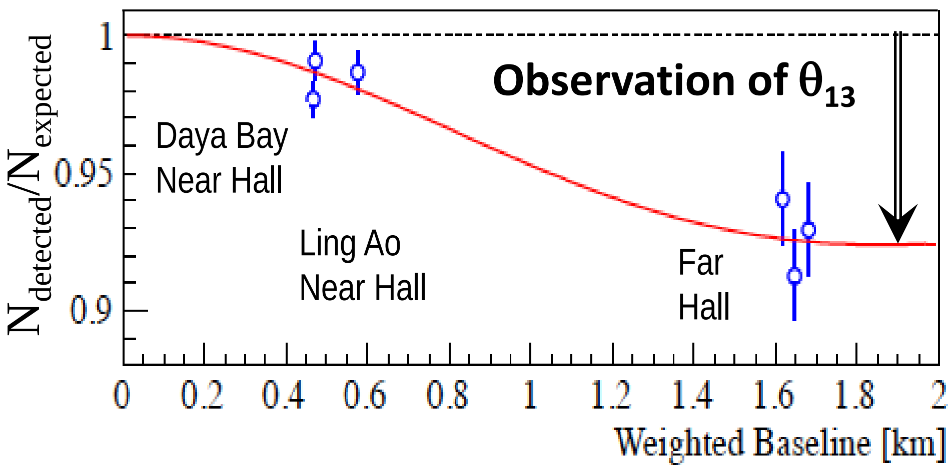
The rate of flavor changing neutrino oscillations

The square of the mass difference for neutrino types

The verification of the 3-neutrino model (electron neutrino, mu neutrino, tau neutrino)

A Major Advance in Further Understanding the Standard Model of Particle Physics

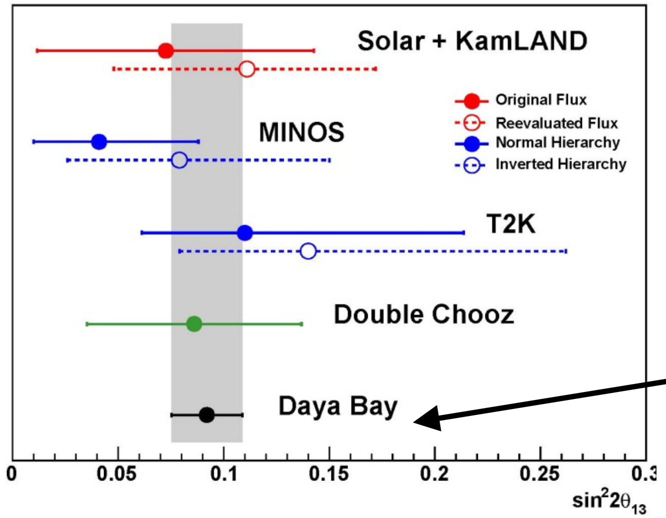
Neutrino mixing angle θ_{13} is non-zero at 5.2σ



It takes a "scientific village"…

NP's contribution: support, along with HEP, of the nuclear chemists' effort on Gadolinium loaded liquid scintillator and materials compatability characterization

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 578, Issue 1, 21 July 2007, Pages 329–339



"Gadolinium-loaded liquid scintillator for high-precision measurements of antineutrino oscillations and the mixing angle, θ_{13}"

M. Yeh, A. Garnov, R.L. Hahn

Chemistry Department, Brookhaven National Laboratory,

$$\sin^2 2\theta_{13} = 0.092 \pm 0.016(\mathrm{stat}) \pm 0.005(\mathrm{syst})$$

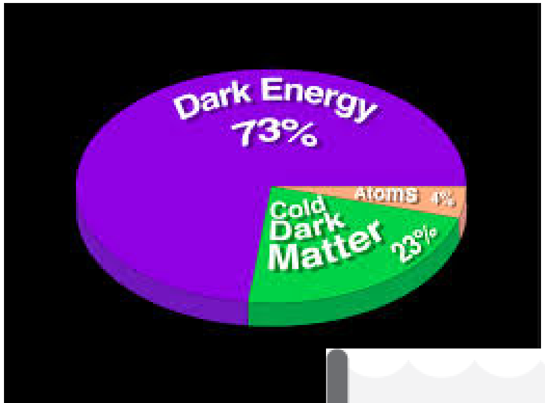
Non-zero θ_{13} enables a clear path forward towards measuring leptonic CP violation.

The importance of the Isotope Gd to the success of Daya Bay

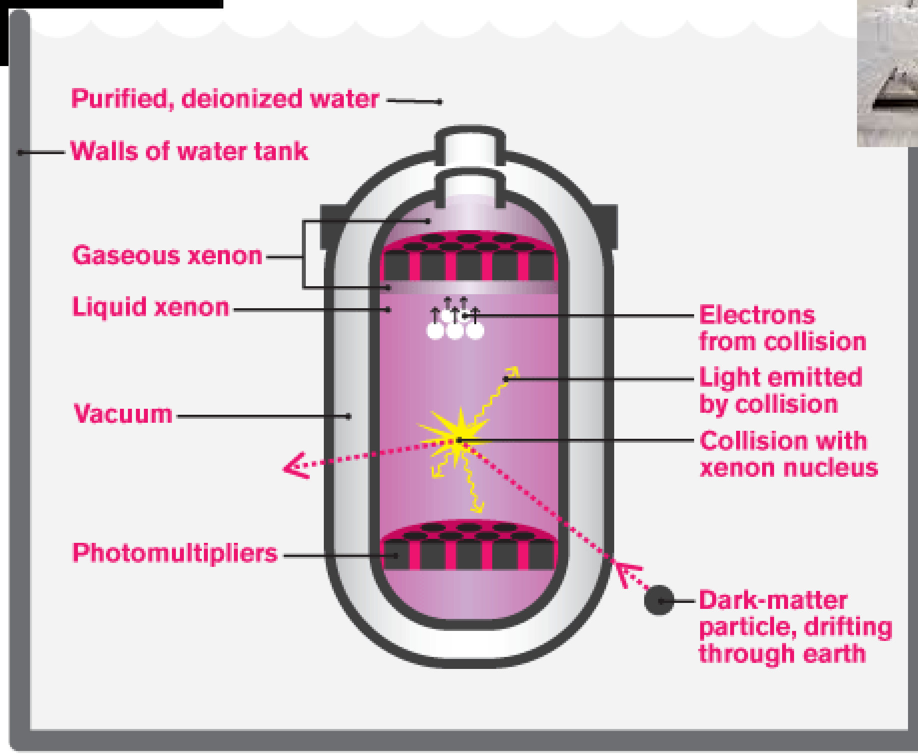
The Daya Bay reactor antineutrino experiment aims for a high-precision measurement of the neutrino mixing angle θ_{13} by searching for $\bar{\nu}_e$ deficiency as a function of distance from a nuclear reactor complex in Shenzhen, China [1-3]. Antineutrinos are detected via the inverse beta-decay (IBD) reaction, $\bar{\nu}_e + p \rightarrow e^+ + n$, in a delayed coincidence between the prompt signal of the positron and the subsequent capture of the neutron in a (n,γ) reaction after it has been thermalized in the scintillator. This delayed coincidence provides a unique $\bar{\nu}_e$ signature and serves as a powerful tool to reduce random backgrounds.

The neutron capture can occur on hydrogen in the liquid scintillator (LS). The cross section is 0.332 barns and the energy of the emitted gamma is 2.2 MeV. There are several important advantages of adding a neutron-capture-enhancing element, such as gadolinium (Gd), to the LS. The (n,γ) cross-section for natural Gd is 49,000 barns (with major contributions from the ^{155,157}Gd isotopes), that only a small concentration of Gd, e.g. 0.1% by mass, is necessary. The neutron-capture on Gd releases 8-MeV of energy in a cascade of 3-4 γ-rays that can easily exclude the low-energy backgrounds from natural radiations in the surrounding environment. Furthermore, the neutron-capture time is significantly shortened to ~28 μs in a 0.1% Gd-LS, as compared to ~200 μs in LS. This shortened delay time reduces the accidental background rate by a factor of 7.

Further Importance of Isotopes in HEP:



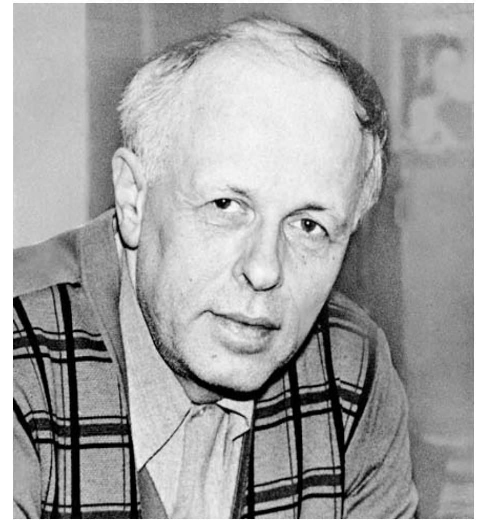
Figuring out what the other 97% of our universe is actually made of



LUX detector at Sanford Underground Research Facility

Going to the Heart of the Matter Physics-Wise, Why Do We Exist ?

Because there is more matter than anti-matter in today's universe



Sakharov Conjecture: For that to occur, necessary (but not sufficient) conditions are:

NP experiments → 1. At least one Baryon-number violating process.

HEP experiments→ 2. C- and CP-violation

3. Interactions outside of thermal equilibrium.

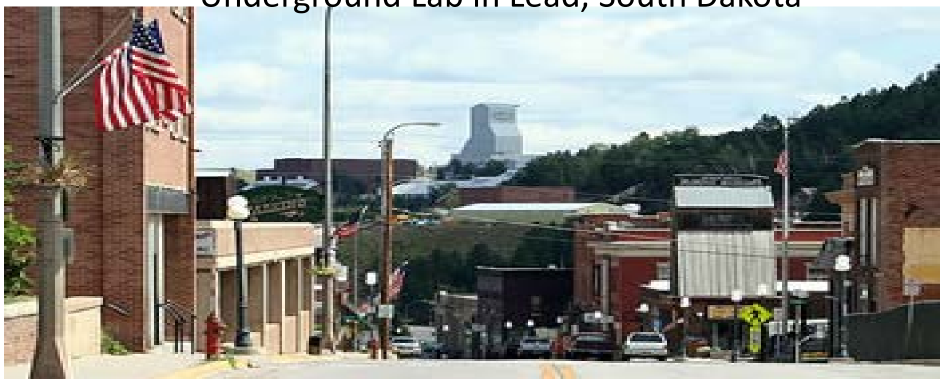
Particles	A + C = D + E
	D + π→ p + n
Baryon Number	2 + 0 = 1 + 1

Example of Baryon Number Conservation

A Related Question is Whether Lepton Number is Conserved ?

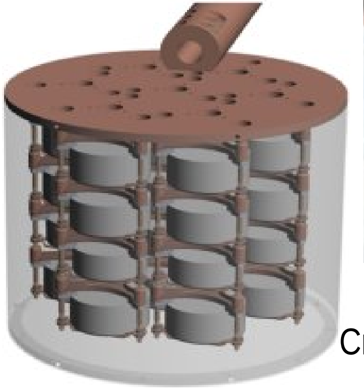
That Grand challenge question is being tackled by a sensitive search for neutrino-less double beta decay?

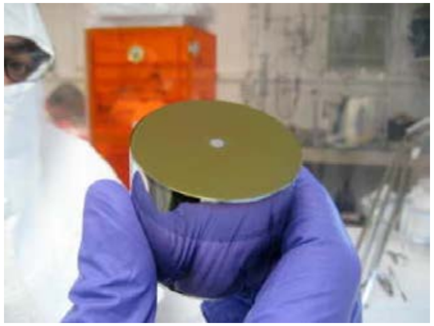
Underground Lab in Lead, South Dakota



- An R&D effort on the Majorana Demonstrator (MJD) will help establish the feasibility of a tonne-scale ^{76}Ge neutrino-less double beta-decay experiment.
- The MJD technology demonstration is planned prior to a down-select between competing technologies for a ton-scale experiment
- MJD is on track with electroforming and with procurement and processing of enriched Ge.

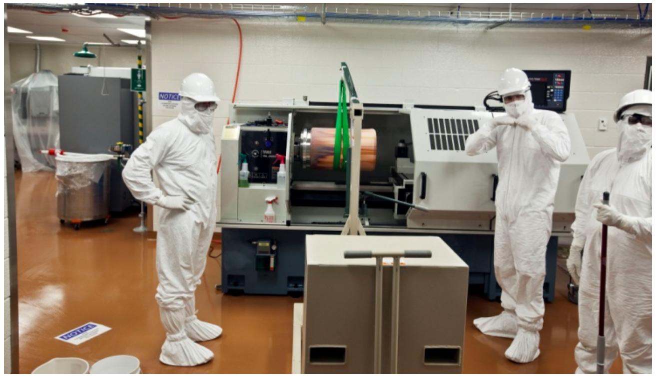
Germanium detector and the cryostat for the Majorana Demonstrator (MJD 40-kg ultra-clean Ge detector).



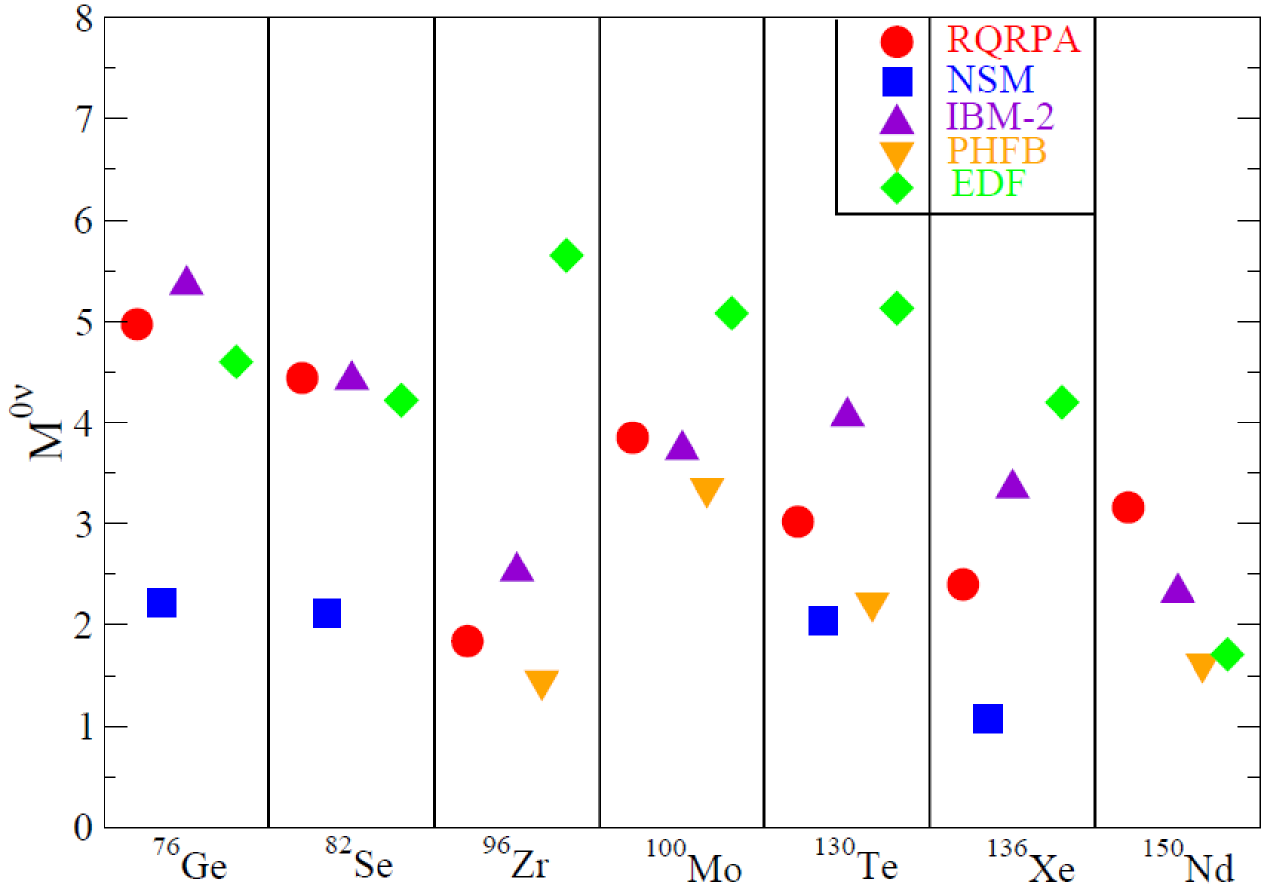


Cryostat for MJD

MJD Underground Electroforming lab at Sanford

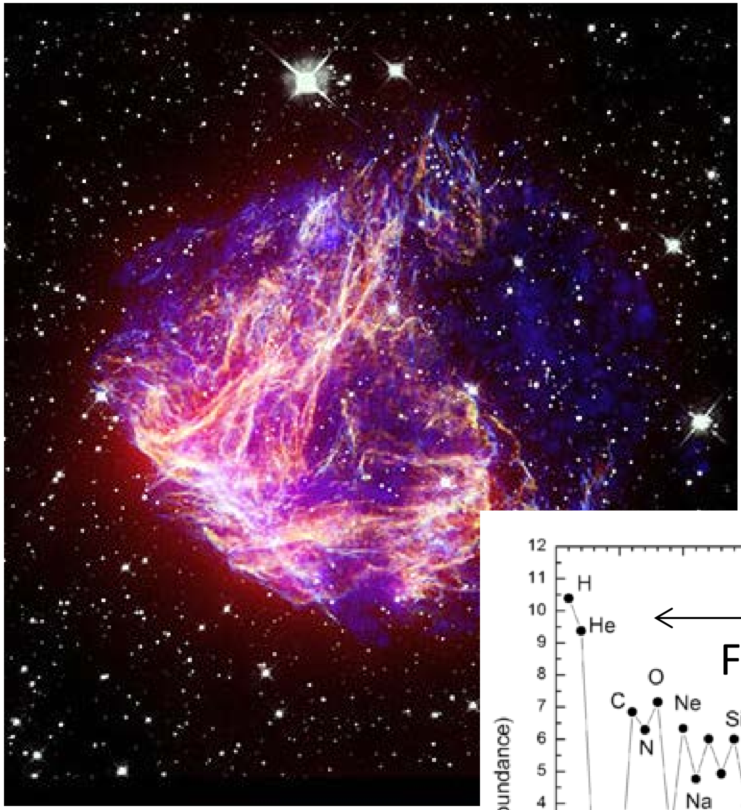


Is 76 Ge the only Isotope of Interest?



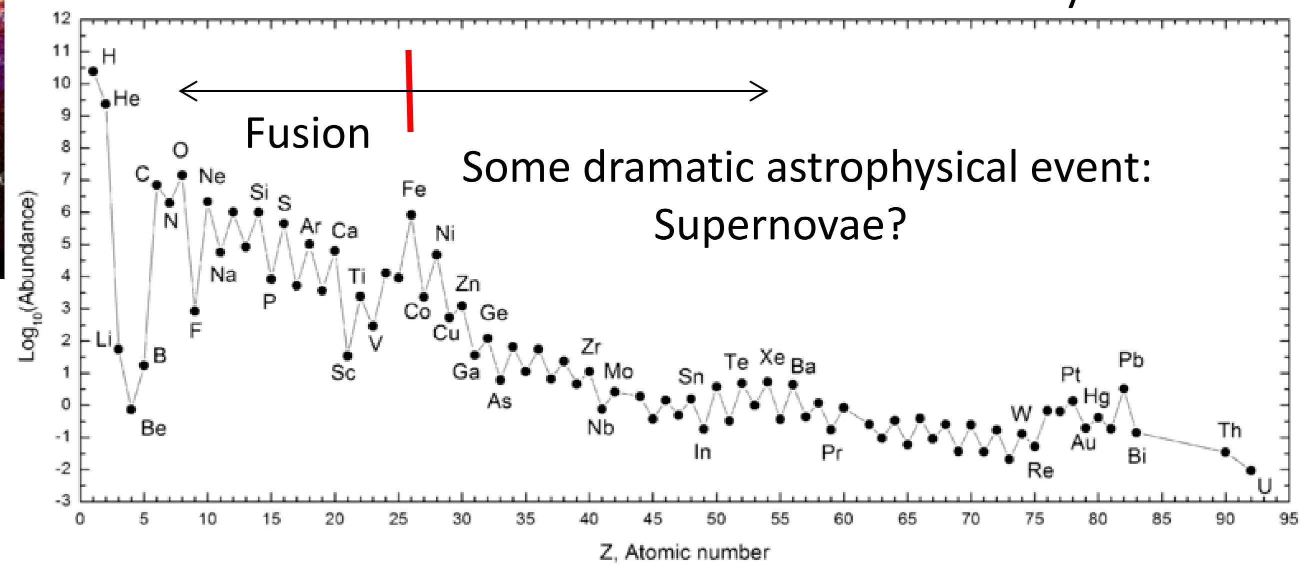
A key element for correct interpretation is the "Nuclear Matrix Element" for a given isotope. As the calculation of these varies, it is essential that more than one isotope be used.

Origin of the Elements?



This is a composite image of N49, the brightest supernova remnant in optical light in the Large Magellanic Cloud. The Chandra X-ray image (blue) shows million-degree gas in the center. Much cooler gas at the outer parts of the remnant is seen in the infrared image.

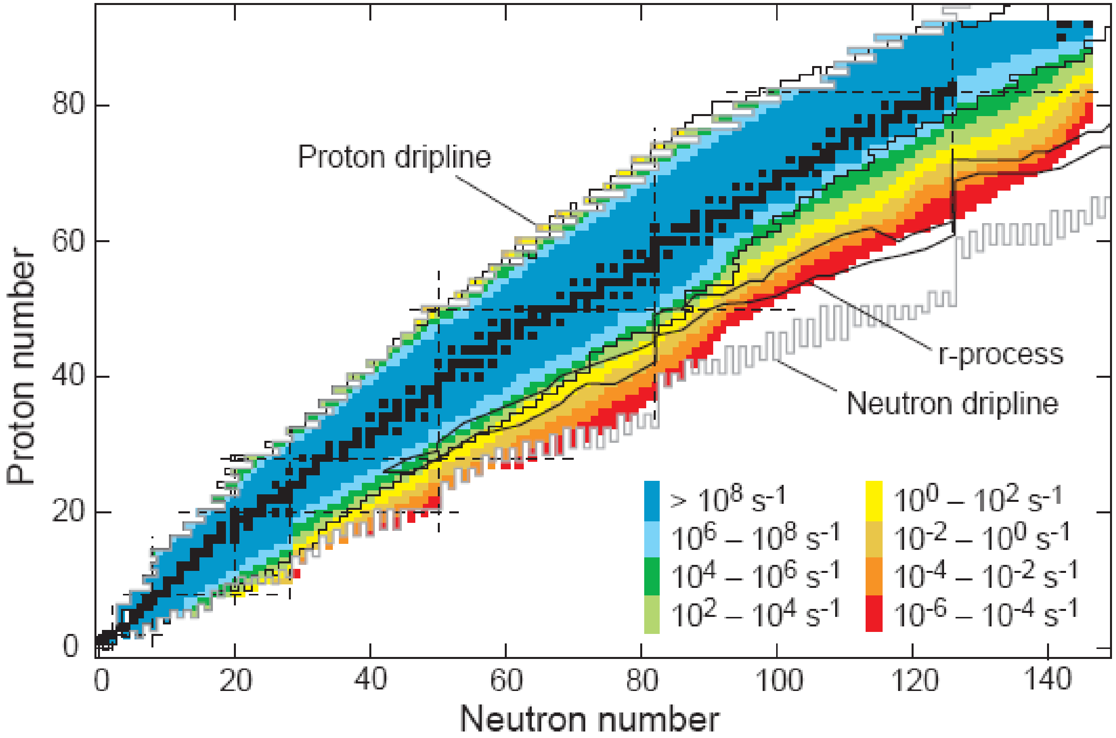
Elemental Abundances in our Solar System



Understanding the Origin of the Elements is All About Isotopes

Possible New Paradigm for Production of Heavier Elements: Neutron STAR Mergers

But we can' tell for sure yet, because we don't know the rates for many nuclear reactions, particularly for nuclei with an excess of neutrons



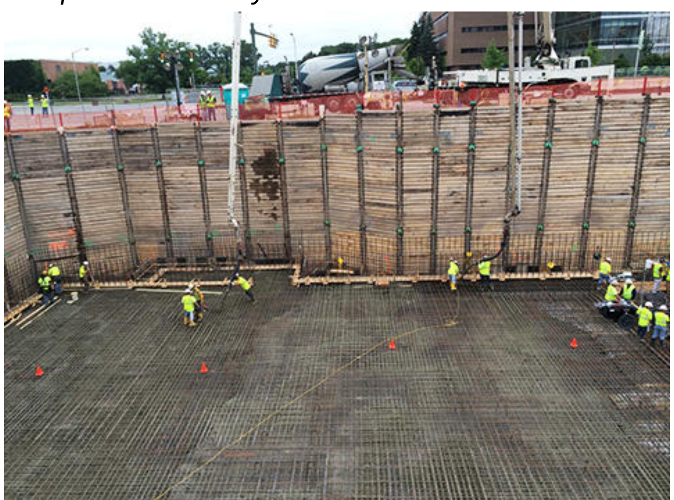
That answer will come from the Facility for Rare Isotope Beams

Construction of the Facility for Rare Isotope Beams at MSU

Ground breaking ceremony on March 17, 2014.

In July 2014, 140 truckloads of concrete arrived at MSU.

Workers placing 1,400 cubic yards of concrete in the first structural concrete placement in July for the linear accelerator tunnel.



Research Related to Isotopes Even Touches ASCR

Silicon Shovels for Rare-Earth Solutions
Office of Science scientists use supercomputers to search for innovative answers to rare-earth supply needs.

Our lives depend on our electronics – our cellphones and computers. In turn, our electronics depend on a special class of elements known as rare-earths. Computers, cellphones, electric vehicles, televisions, and more are built using these materials. Their value lies in their unique properties; some are strongly magnetic; others create vivid colors for optical uses.
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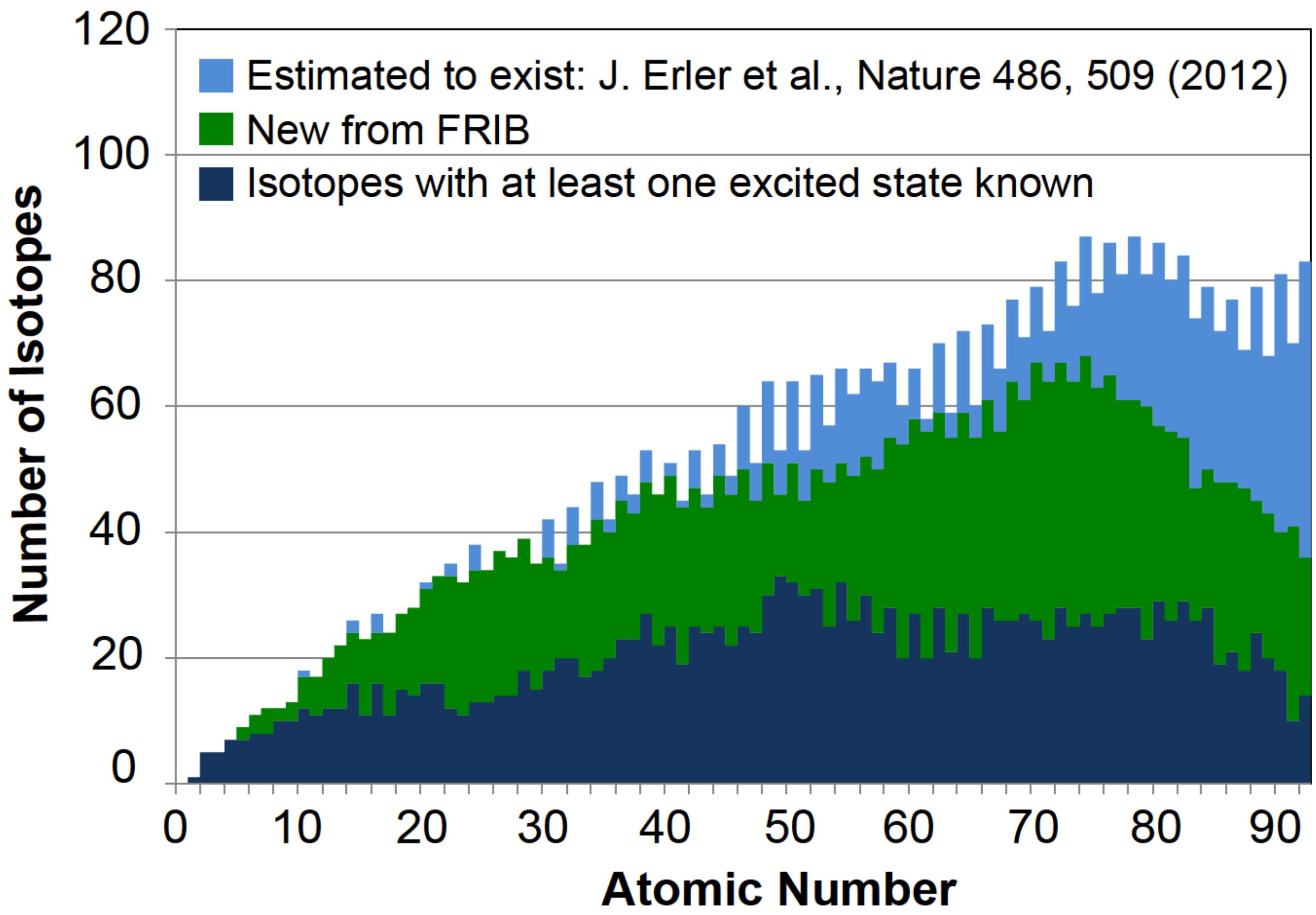
A photo of four voice coil magnets taken from a desktop or laptop computer and their brackets (which have mounting holes). These magnets are each about 10.5 - 15 grams, 1 - 1.25 inches long. These ones are colorful, because they have been overheated in the process of separation and demagnetization.

Using data produced during 5 million core hours of research generated by CMI associate Nuwan De Silva on the supercomputer Titan, Windus' team will design ligands – molecules that attach with a specific rare-earth – that allow metallurgists to extract elements with minimal contamination from surrounding minerals. Through this simplified processing, savings in time and labor will increase the availability of these vital rare-earths.
"A refrigerator magnet is the lowest of the permanent magnets, used to hold your child's drawing to the front of the fridge. We want to make a refrigerator magnet that will hold the Manhattan phone book to the fridge door."

A More Direct Example of ASCR Research Related to Isotopes



Results of an ACSR simulation (SciDAC) on the full extent of isotopes that may exist

ATTA-3 at ANL to be Used to Map Major Aquifers around the World

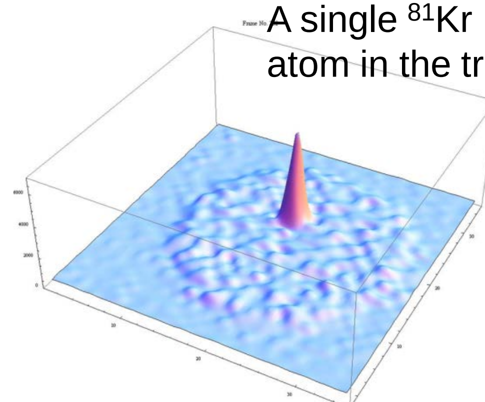
Developed ATTA-3 instrument with greatly improved sensitivity and selectivity

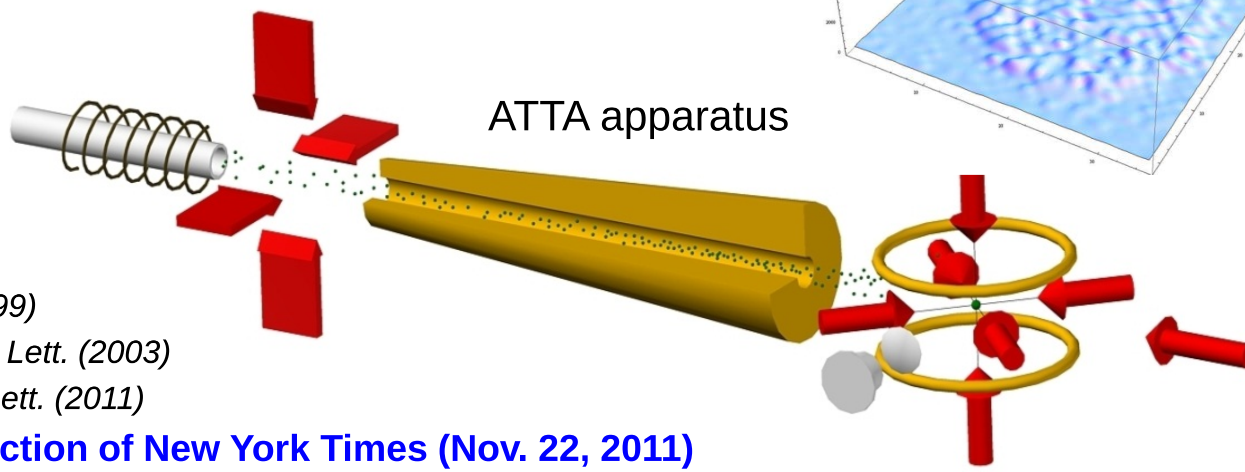
- Sensitivity: Capable of ^{81}Kr-dating with a sample of 10 micro-liter (STP) of krypton gas;
- Selectivity: Analyzed ^{39}Ar in environmental samples at the isotopic abundance level of 8×10^{-16}.

^{81}Kr-dating realized with a range of applications in earth & environmental sciences

Samples to be analyzed in 2011-2012

- Done: Yellowstone National Park, WIPP sites (with Sandia);
- In progress: Great Artesian Basin, Australia;
- In plan: Participate in a comprehensive study of world-wide aquifers (with IAEA).





References

- ATTA-1: *Chen et al., Science (1999)*
- ATTA-2: *Du et al., Geophys. Res. Lett. (2003)*
- ATTA-3: *Jiang et al., Phys. Rev. Lett. (2011)*
- **Featured in the Science Section of New York Times (Nov. 22, 2011)**

Nuclear Science Capability Developed by NP "In The News"

The New York Times SCIENCE

A Rare Isotope Helps Track an Ancient Water Source

By FELICITY BARRINGER
Published: November 21, 2011

DEA/C. SAPPA/De Agostini/Getty Images

The Dakhla Oasis in western Egypt is fed by the Nubian Aquifer.

Knowing how long water has been underground helps researchers understand how fast aquifers are recharged by surface water and how fast they move, leading to more accurate geological models. Groundwater is becoming an increasingly crucial component of the world's available fresh water, and the findings could significantly increase understanding of how it behaves. …

The Nubian Aquifer, the font of fabled oases in Egypt and Libya, stretches languidly across 770,000 square miles of northern Africa, a pointillist collection of underground pools of water migrating, ever so slowly, through rock and sand toward the Mediterranean Sea.

The aquifer is one of the world's oldest. But its workings — how it flows and how quickly surface water replenishes it — have been hard to understand, in part because the tools available to study it have provided, at best, a blurry image.
Now, to solve some of the puzzles, physicists at the Department of Energy's Argonne National Laboratory in Illinois have turned to one of the rarest particles on earth: an elusive radioactive isotope usually ricocheting around in the atmosphere at hundreds of miles an hour.

Their first success was in distilling these elusive isotopes, krypton 81, from the water in the huge Nubian Aquifer, part of which lies two miles below the oases of western Egypt where temples honor Alexander the Great. Their second was in holding these isotopes still and measuring how much they had decayed since they last saw sunlight.
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R&D Creates New Production Method for Actinium-225

- A new isotope project at LANL shows promise for rapidly producing major quantities of a new cancer-treatment agent, actinium 225.
- Using proton beams, LANL and BNL could match current annual worldwide production of the isotope in just a few days.
- A collaboration among LANL, BNL, and ORNL is developing a plan for full-scale production and stable supply of Ac-225.
- Ac-225 emits alpha radiation. Alpha particles are energetic enough to destroy cancer cells but are unlikely to move beyond a tightly controlled target region and destroy healthy cells. Alpha particles are stopped in their tracks by a layer of skin—or even an inch or two of air.

Outlook

More than ever before isotopes are intrinsically fundamental to all manner of basic science and applied research. Asking whether research needs isotopes is like asking whether people need water to survive.

More than ever before, knowledge of the detailed properties, structure, decays, production and separation techniques is allowing scientists to develop "designer" solutions to problem that may previously have been completely intractable. This knowledge allows us to look further backward in time, deeper into the oceans, further into our environmental future, deeper into our own physiology and more insightfully into the materials that surrounds us.

More than ever before there is a coordinated effort by the DOE Isotope program to enhance that knowledge and provide access to isotopes for research that will advance us as a society.

Facility for Rare Isotope Beams

FRIB will increase the number of isotopes with known properties from ~2,000 observed over the last century to ~5,000 and will provide world-leading capabilities for research on:

Nuclear Structure

- The ultimate limits of existence for nuclei
- Nuclei which have neutron skins
- The synthesis of super heavy elements

Nuclear Astrophysics

- The origin of the heavy elements and explosive nucleo-synthesis
- Composition of neutron star crusts

Fundamental Symmetries

- Tests of fundamental symmetries, Atomic EDMs, Weak Charge

This research will provide the basis for a model of nuclei and how they interact.

Project received CD-3B, *Approval to Start Technical Construction*, on August 26, 2014.

Five of fifteen nonconventional utility process tanks to be installed during conventional construction.