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U.S. DEPARTMENT OF ENERGY

Nuclear Data and Applied Nuclear Science

Libby McCutchan (NNDC,BNL)
mccutchan@bnl.gov

Nuclear Data Program

Link between basic science and applications

Nuclear Science Community

- experiments
- theory

Nuclear Data Community

✦ compilation
✦ evaluation
✦ dissemination
✦ archival

Applications Community

needs data:
✦ complete
✦ organized
✦ traceable
✦ readable

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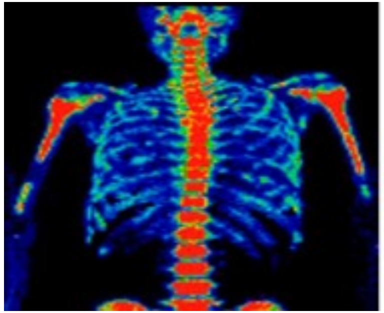
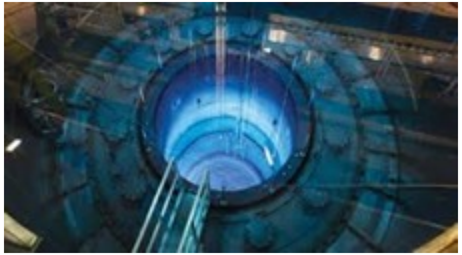
Applications of Nuclear Data



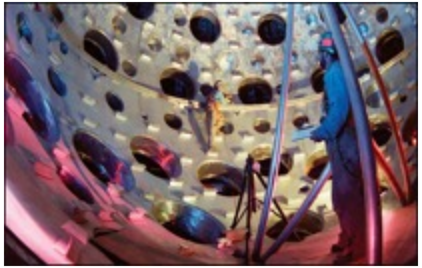
Nuclear Medicine

How can I produce and use radioactive isotopes in the body?



Nuclear Power

Is there new physics beyond the standard model and can we make the world safer?



Stockpile Stewardship

How do you ensure something will work after decades on the shelf?

Homeland Security

Space Exploration

How do I determine what's in something I can't see or touch?

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Want more fun facts about nuclei?

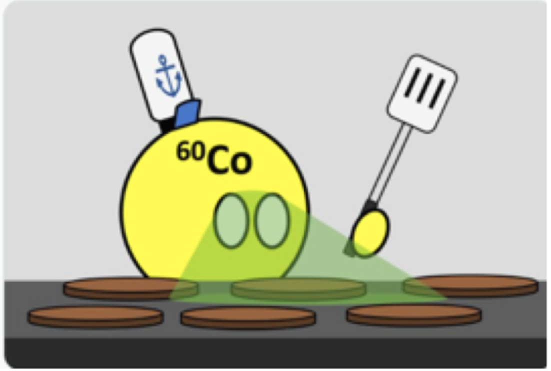
National Nuclear Data Center @NNDC_BNL · Feb 14
Tritium (3-Hydrogen), combined with phosphor (a material that emits light when exposed to radiation), leads to radioluminescence. This glow can be used to illuminate the hands of sport watches. #NuclideSpotlight #ScienceValentines

Follow us on Twitter!!
@NNDC_BNL

National Nuclear Data Center @NNDC_BNL · Oct 20, 2021
#NuclideSpotlight

Gamma rays can be used to kill bacteria and extend the shelf-life of food products.

This process (called "food irradiation") commonly uses 60-Cobalt, which:
- has a long half-life
- emits high-intensity gamma rays
- does not easily dissolve into water



National Nuclear Data Center @NNDC_BNL · Nov 12, 2021
#NuclideSpotlight
#History

95m- and 97-Technetium were discovered in 1937 during an investigation of irradiated cyclotron parts.
Neither isotope occurs naturally, which made this the first study of synthetic elements produced by human beings.

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Nuclear Medicine

What can we use radioisotopes for in medicine?

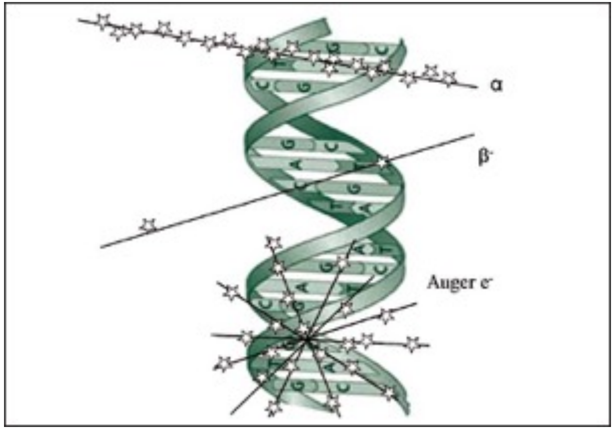
Imaging

X-rays, gamma rays

Therapy

Alphas, betas, Auger electrons

Targeted Radionuclide Therapy



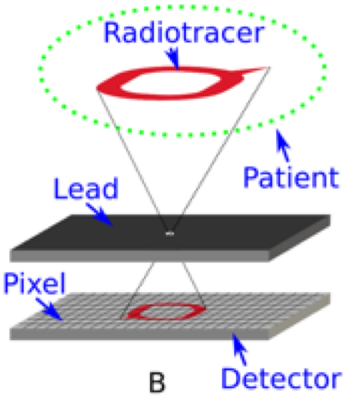
M. Sadeghi et al., J Can Res Ther 2010;6:239

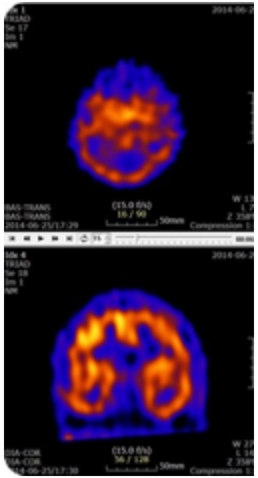
- Ionizing radiation to kill cancer cells and shrink tumors
- Uses molecule labeled with radionuclide

Diagnostic Imaging with Radioisotopes

SPECT

Single Photon Emission Tomography

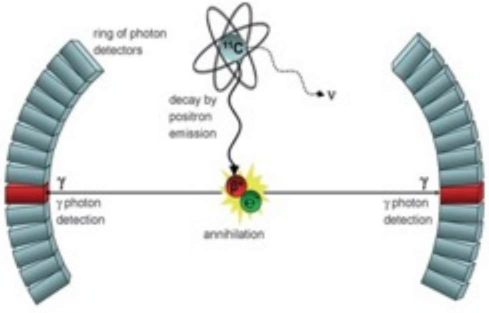


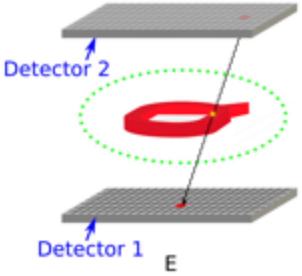


^{99m}Tc, ^{123}I, ^{121}I, ^{67}Ga, ^{201}Tl

PET

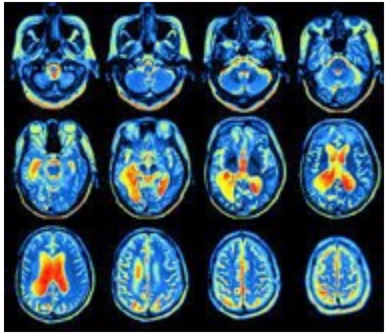
Positron Emission Tomography





Miller et. al. Angewandte Chem. Int. Ed. 47, 8998, 2008

^{18}F, ^{82}Rb, ^{13}N, ^{66}Ga



As an example : ^{86}Y

IOP Publishing | Institute of Physics and Engineering in Medicine — Physics in Medicine & Biology
Phys. Med. Biol. 60 (2015) 3479–3497 doi:10.1088/0031-9155/60/9/3479

PET imaging with the non-pure positron emitters: ^{55}Co, ^{86}Y and ^{124}I

P E N Braad[1], S B Hansen[2], H Thisgaard[1] and

Eur J Nucl Med Mol Imaging (2016) 43:925–937
DOI 10.1007/s00259-015-3254-8

ORIGINAL ARTICLE

PHYSICAL REVIEW C VOLUME 2, NUMBER 6 DECEMBER 1970

Energy Levels in ^{86}Sr from the Decay of 14.6-h ^{86}Y

A. V. Ramayya, B. Van Nooijen,* J. W. Ford, D. Krmpotić,† and J. H. Hamilton
Physics Department,‡ Vanderbilt University, Nashville, Tennessee 37203

and

J. J. Pinajian and Noah R. Johnson
Oak Ridge National Laboratory,§ Oak Ridge, Tennessee 37803
(Received 20 April 1970)

ELSEVIER journal homepage: www.elsevier.com/locate/apradiso

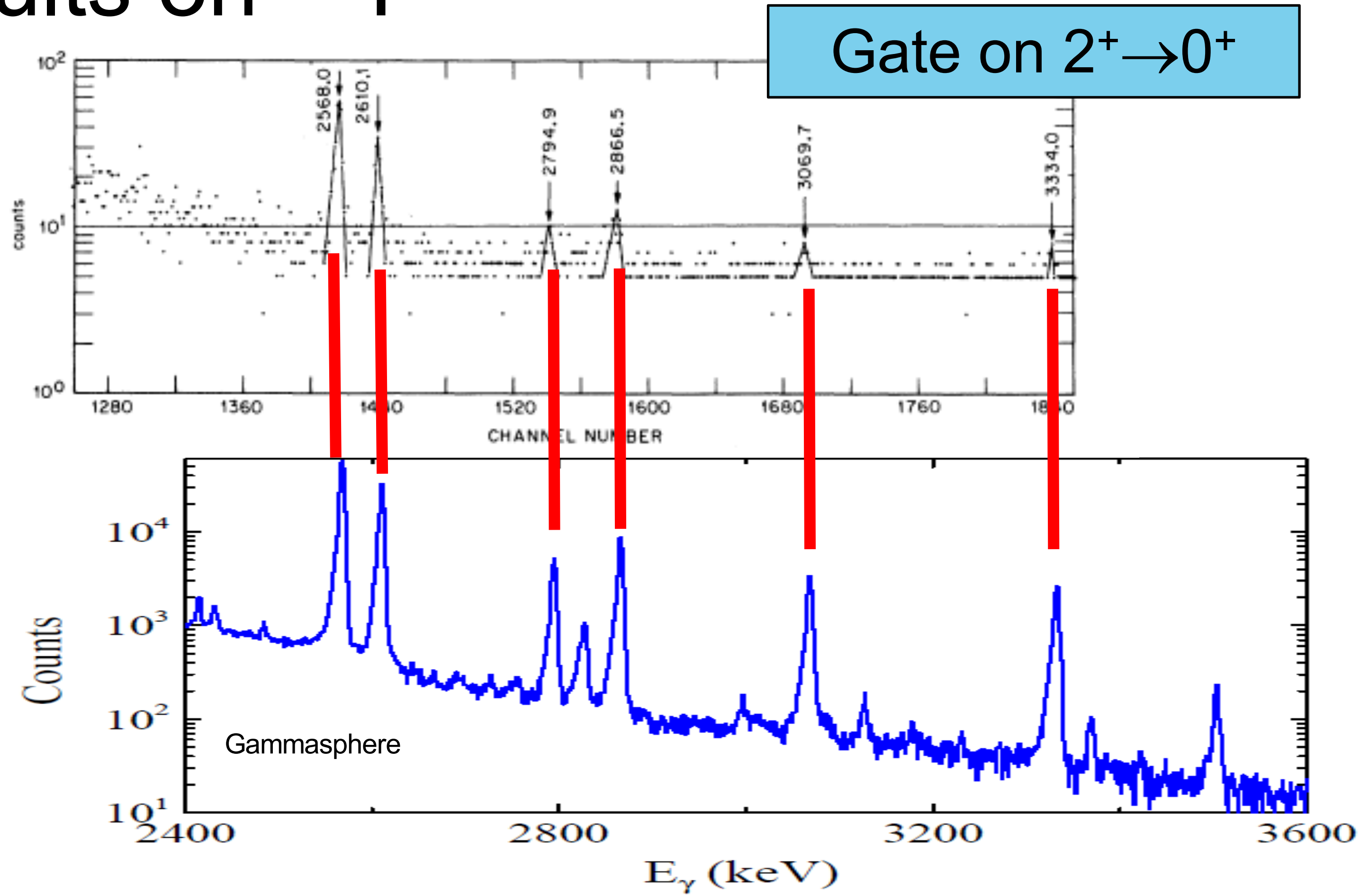
Tailoring medium energy proton beam to induce low energy nuclear reactions in $^{86}SrCl_2$ for production of PET radioisotope ^{86}Y☆

CrossMark

Dmitri G. Medvedev*, Leonard F. Mausner, Philip Pile

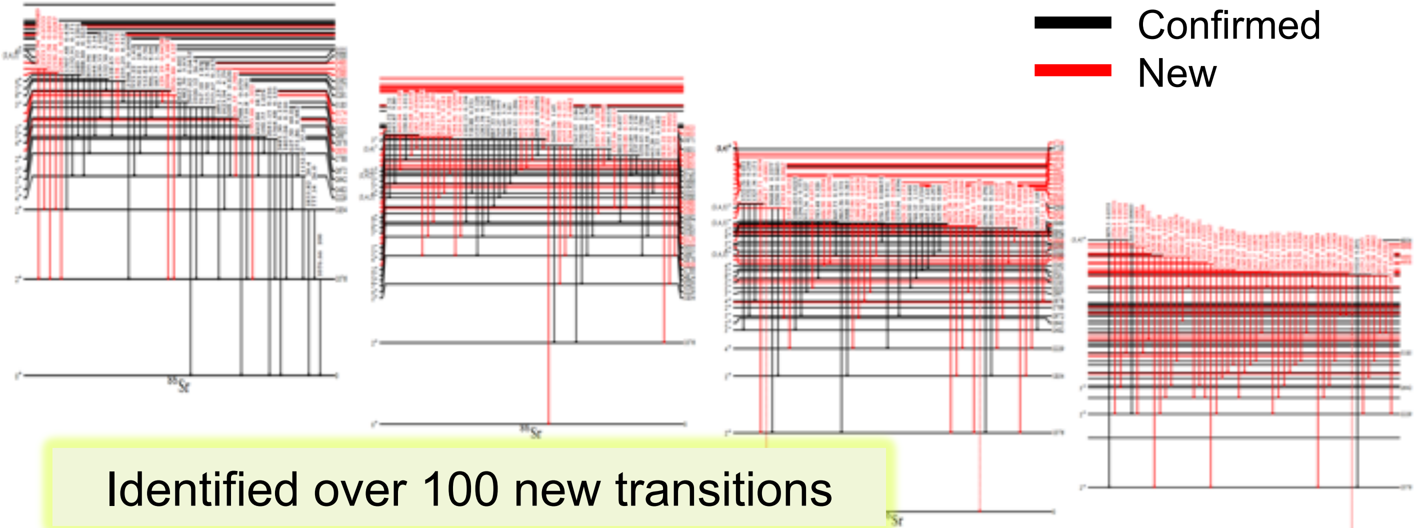
Brookh
National La

Results on ^{86}Y



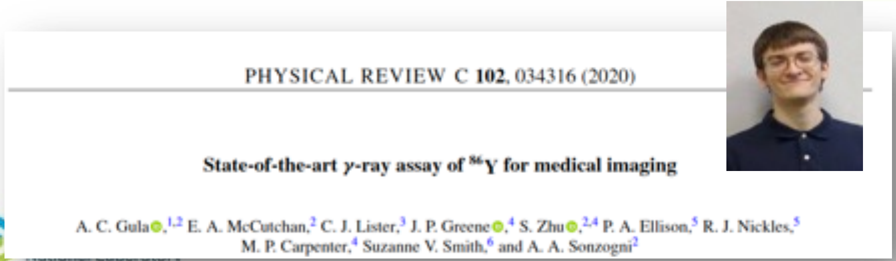
Revised Decay Scheme for ^{86}Y

Confirmed
New



Identified over 100 new transitions

511-keV intensity decreases by 15% !

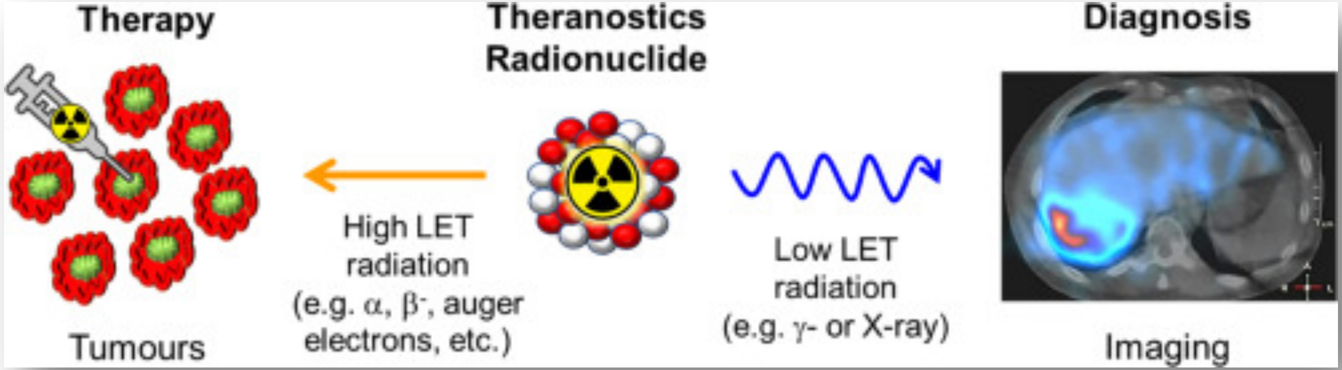


PHYSICAL REVIEW C **102**, 034316 (2020)

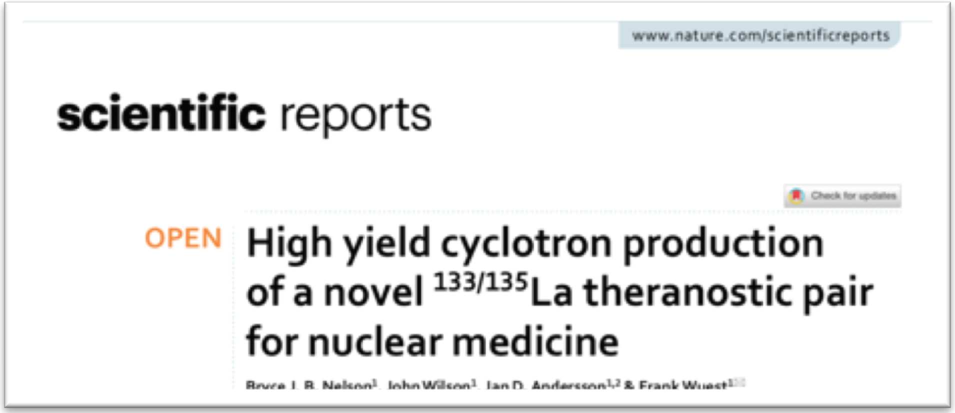
State-of-the-art γ-ray assay of ^{86}Y for medical imaging

A. C. Gula,[1,2] E. A. McCutchan,[2] C. J. Lister,[3] J. P. Greene,[4] S. Zhu,[2,4] P. A. Ellison,[5] R. J. Nickles,[5] M. P. Carpenter,[4] Suzanne V. Smith,[6] and A. A. Sonzogni[2]

The Future : Theranostics



H.Y. Tan *et al.*, Nucl. Med. Biology **90**, 55 (2020).



www.nature.com/scientificreports

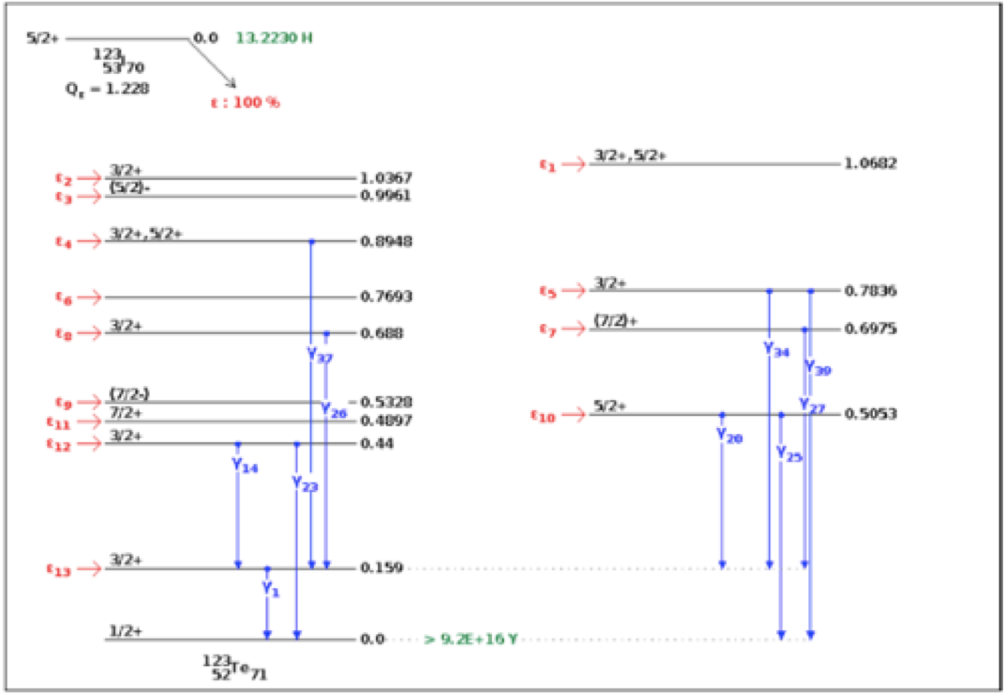
scientific reports

Check for updates

OPEN **High yield cyclotron production of a novel $^{133/135}$La theranostic pair for nuclear medicine**

Bryce J. B. Nelson[1], John Wilson[1], Jan D. Andersson[1,2] & Frank Wuest[1]

MIRD – yes we have an app for that !
Medical Internal Radiation Dosimetry

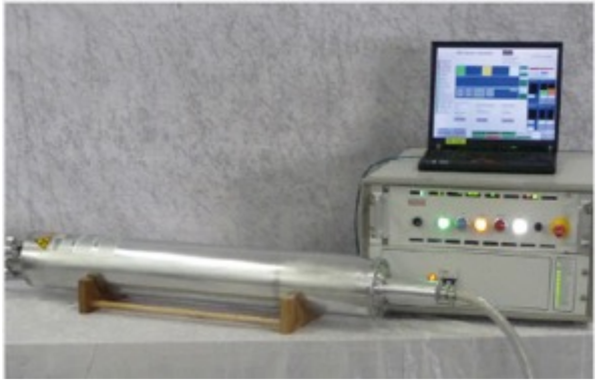


53-IODINE-123
Half-life = 13.2230 Hours
Decay modes: ε
References:
123I EC DECAY (13.2230 H)

Download as .csv

Radiations	γ(i) $(Bq\text{-}s)^{-1}$	E(i) (MeV)	γ(i)×E(i)
γ_1	8.36×10^{-1}	1.589×10^{-1}	1.32×10^{-1}
ce-K, γ_1	1.34×10^{-1}	1.271×10^{-1}	1.71×10^{-2}
ce-L, γ_1	1.74×10^{-2}	1.540×10^{-1a}	2.69×10^{-3}
ce-M, γ_1	3.48×10^{-3}	1.579×10^{-1a}	5.50×10^{-4}
γ_{14}	7.19×10^{-4}	2.810×10^{-1}	2.02×10^{-4}
γ_{20}	1.20×10^{-3}	3.463×10^{-1}	4.15×10^{-4}
γ_{23}	3.88×10^{-3}	4.400×10^{-1}	1.70×10^{-3}
γ_{25}	2.88×10^{-3}	5.053×10^{-1}	1.45×10^{-3}
γ_{26}	1.27×10^{-2}	5.289×10^{-1}	6.71×10^{-3}
γ_{27}	3.10×10^{-3}	5.385×10^{-1}	1.66×10^{-3}
γ_{34}	7.80×10^{-4}	6.245×10^{-1}	4.87×10^{-4}
γ_{37}	4.70×10^{-4}	7.358×10^{-1}	3.45×10^{-4}
γ_{39}	5.30×10^{-4}	7.835×10^{-1}	4.15×10^{-4}
L X-ray	8.96×10^{-2}	$3.770\times10^{-3*}$	3.37×10^{-4}
Kα2 X-ray	2.47×10^{-1}	2.720×10^{-2}	6.71×10^{-3}
Kα1 X-ray	4.56×10^{-1}	2.747×10^{-2}	1.25×10^{-2}
Kβ3 X-ray	4.20×10^{-2}	$3.094\times10^{-2*}$	1.30×10^{-3}

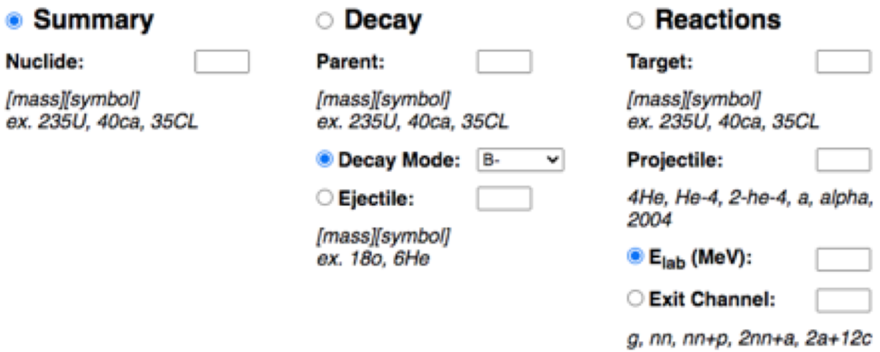
Active Interrogation with Neutrons



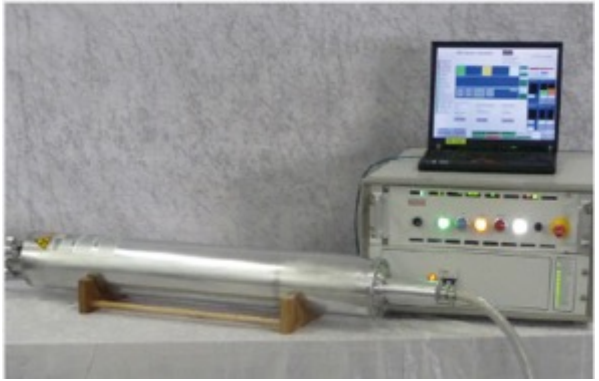
Compact DT neutron generators

Fusion of deuterium and tritium is convenient way to produce high energy neutrons

Using our Q-calc tool – what is the Q value for the reaction?

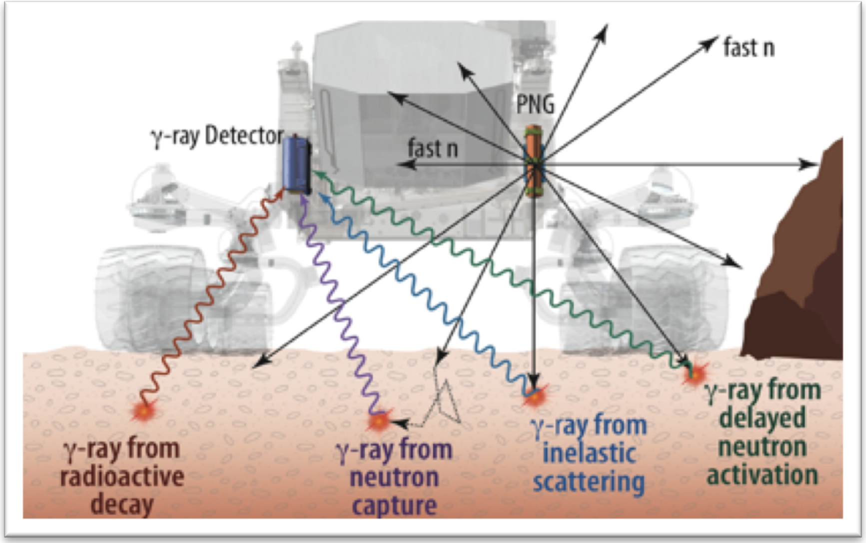


Active Interrogation with Neutrons



Compact DT neutron generators

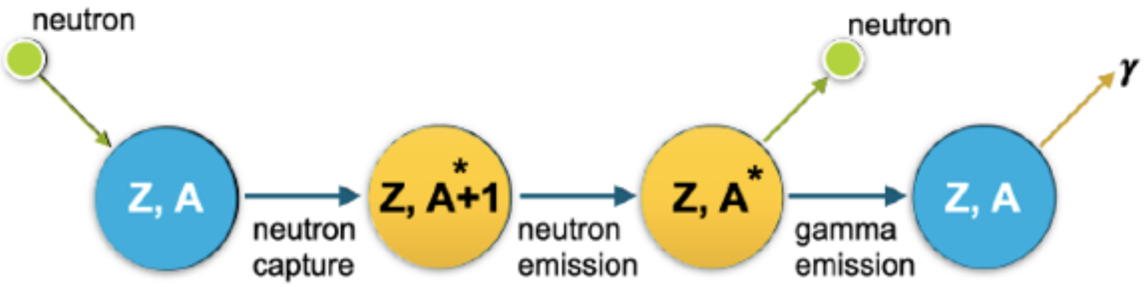
Use our Q-value calculator tool to find Q values for D+T and reaction products. What energy of neutrons are produced?

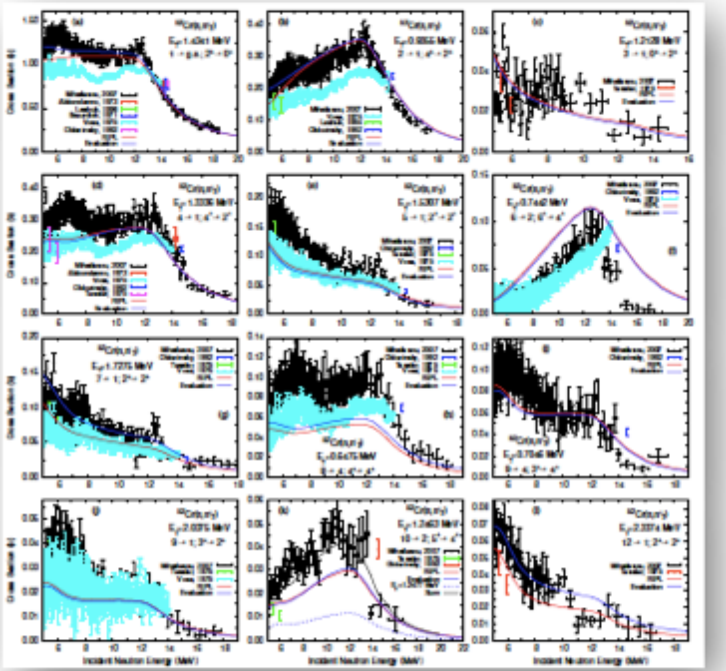


What reactions happen when one shoots MeV-ish neutrons at something?

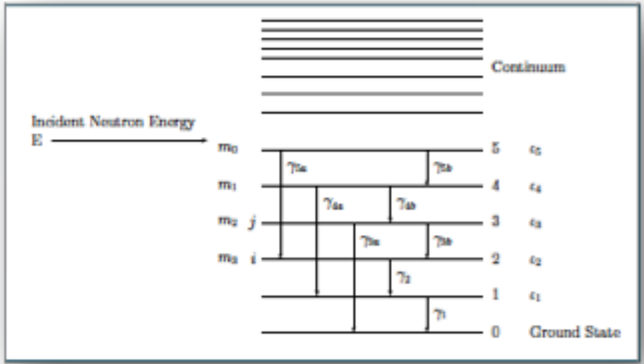
Nowicki, S. F., et al, (2017), Modeled Martian subsurface elemental composition measurements with the Probing In situ with Neutron and Gamma ray instrument, Earth and Space Science, 4, 76–90, doi:10.1002/2016EA000162.

Inelastic reaction gammas





G. Nobre et al., Nucl. Data Sheets 173: 1-41 (2021)

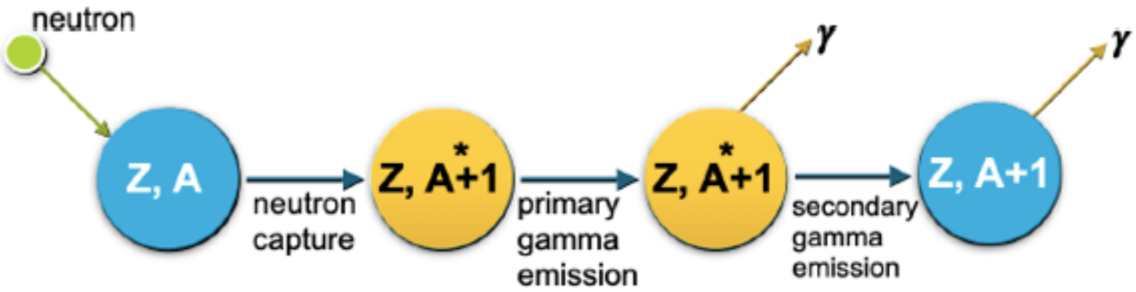


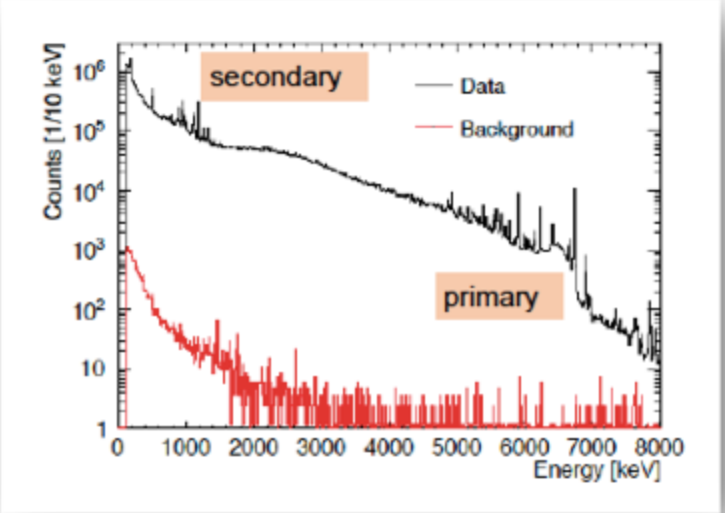
Decay from inelastic state is

- Initially populated by compound reaction
- Cascade lower energy gammas
- Provides a unique fingerprint for each isotope

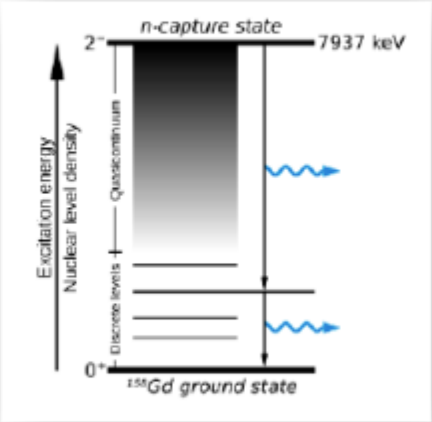
Slide from D. Brown

Thermal neutron capture gammas





K. Hagiwara et al., Prog Theor. Exp. Phys. 0000, 2015



Decay from capture state is

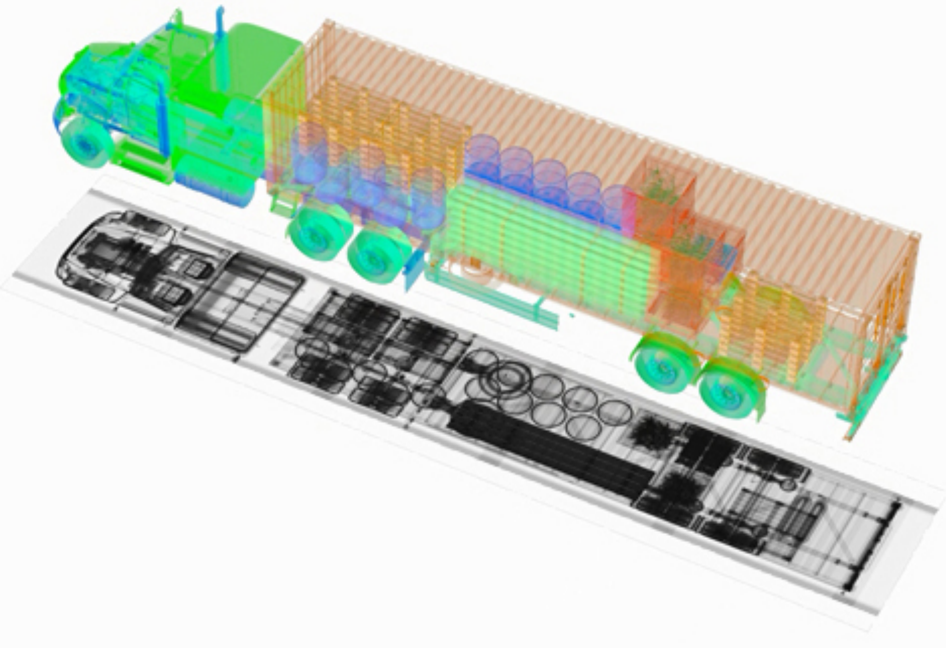
- First high energy gammas - primary
- Followed by lower energy gammas –secondary
- Provides a unique fingerprint for each isotope

What's in the box?

Use a combination of

- Traditional x-rays
- Active neutron interrogation
- NRF

Complete characterization in few minutes



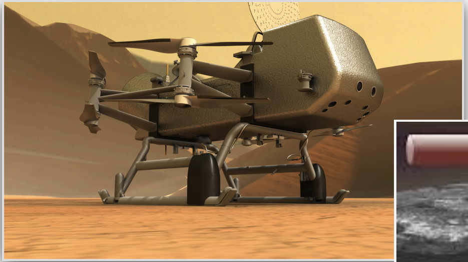
https://passportsystems.com

Slide from D. Brown

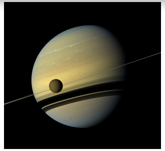
Some additional applications

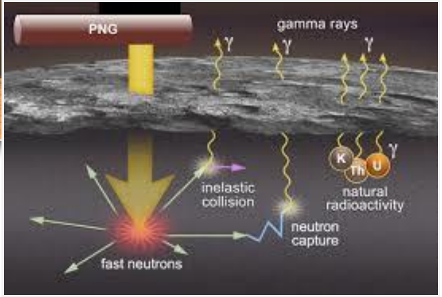
** Images taken from www.nasa.gov, and from Unzueta's, and Mauborgne's talks in WANDA 2020*

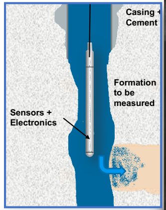
Dragonfly mission to Saturn's moon Titan

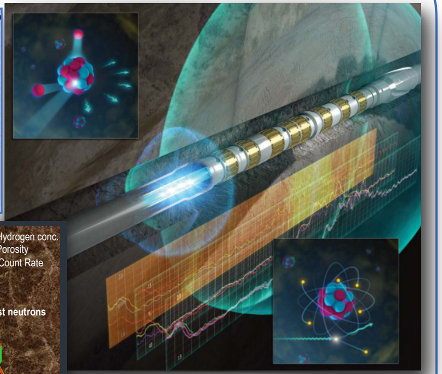


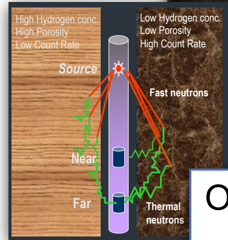
- **Gamma-ray detection system**
  - Thermal neutron capture (TNC)
  - Inelastic Scattering (INS)







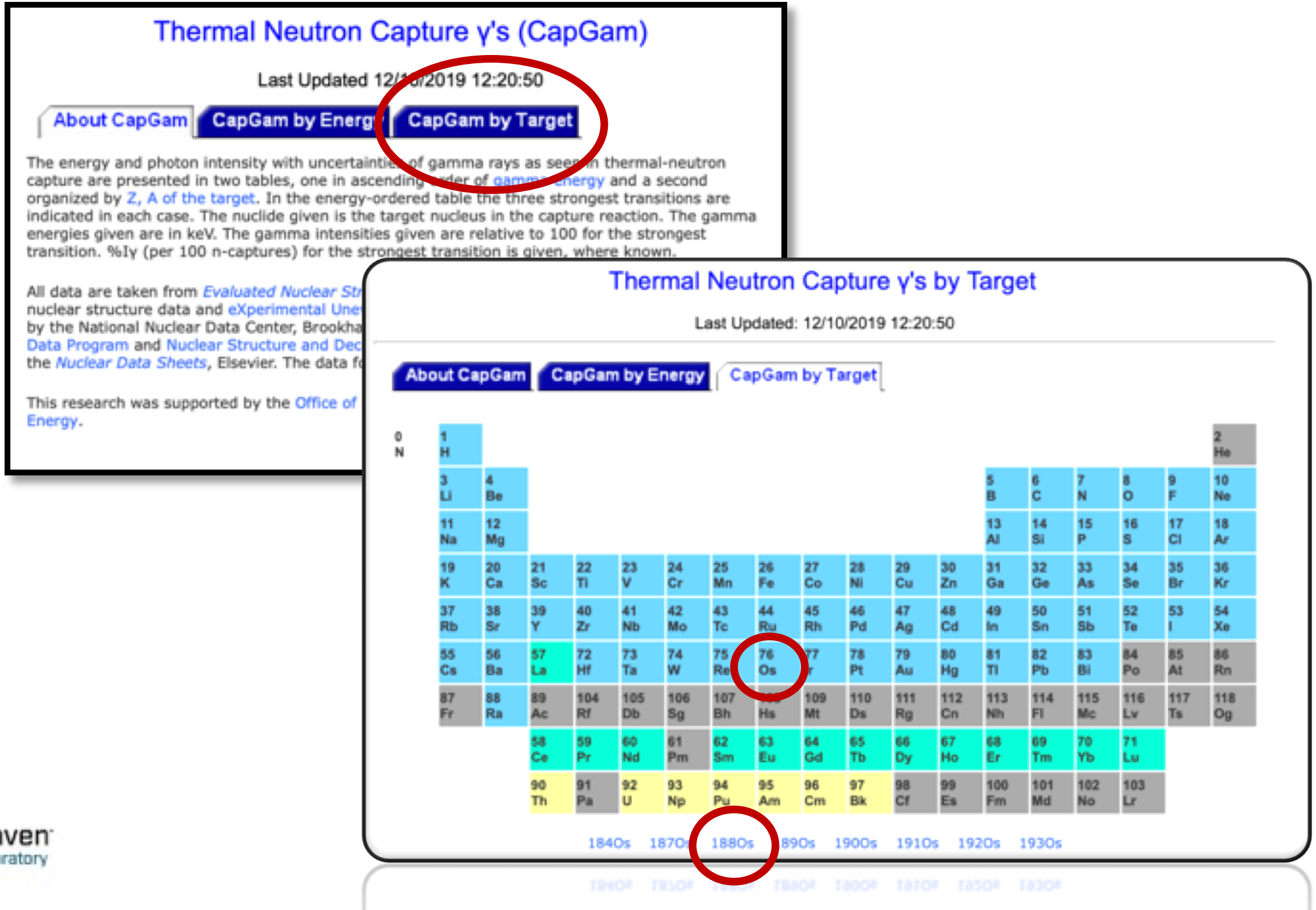




Oil well characterization (Schlumberger)

- Characterization of materials rely on measuring neutron-induced gammas
- These depend on:
  - Precise and thorough experimental knowledge
  - Incorporation of data into evaluated files
  - Proper handling through transport codes, so that information is not lost

CapGam Web Application –



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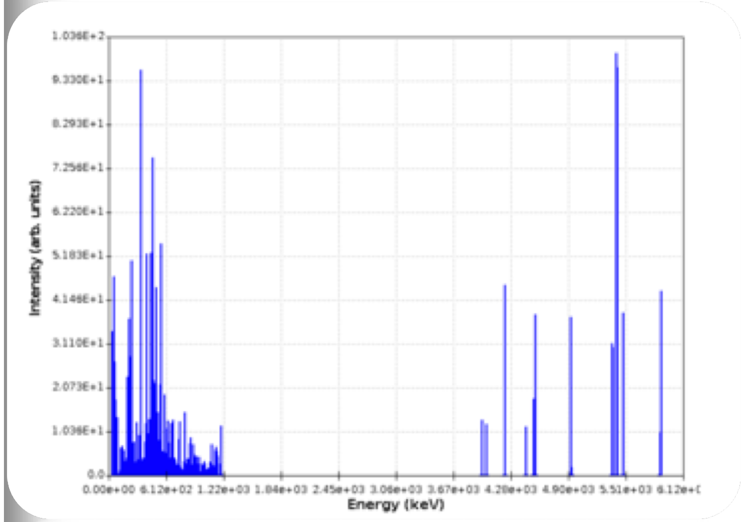
CapGam Web Application

Tabular data and option to download numerical values

Download as .csv

E(γ) (keV)	ΔE(γ) (keV)	$I(\gamma)/I(\gamma)_{max}$ (%)	$\Delta(I(\gamma)/I(\gamma)_{max})$
36.14	*0.04*	33.762	*7.51*
59.08	*0.03*	46.945	*10.43*
64.96	*0.07*	4.18	*1.3*
66.55	*0.04*	26.688	*6.01*
69.55	*0.06*	20.9	*5.83*
95.27	*0.04*	13.505	*2.98*
118.50	*0.09*	0.997	*0.31*
122.47	*0.07*	0.932	*0.23*
124.25	*0.06*	1.0611	*0.26*
129.42	*0.04*	6.141	*1.38*
132.16	*0.05*	2.958	*0.7*
138.30	*0.04*	6.463	*1.43*
147.12	*0.04*	6.817	*1.51*
149.86	*0.04*	5.498	*1.23*
162.74	*0.09*	1.0289	*0.34*
164.03	*0.04*	5.723	*1.28*
175.62	*0.07*	3.0868	*0.79*
181.06	*0.06*	2.605	*0.63*

New feature:
Histogram of intensity vs. energy



Transforming our vast body of data into something unexpected

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What applications come to mind when you think of a nuclear reactor?

- Power
- Decay heat
- Medical isotope production
- Neutrino Oscillations
- Non proliferation

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Antineutrinos from a reactor are a really hot topic

NEWS PARTICLE PHYSICS

Reactor data hint at existence of fourth neutrino

Deficit in antiparticle output exceeds theoretical expectations

BY RON COWEN

GHOST FINDER New results of experiments at the Daya Bay neutrin
the existence of a lightweight sterile neutrino, about one-millionth th

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SHARE

The Daya Bay Reactor Neutrino Experiment studies antineutrinos from six reactors near Shenzhen, China.

Weird sterile neutrinos may not exist, suggest new data from nuclear reactors

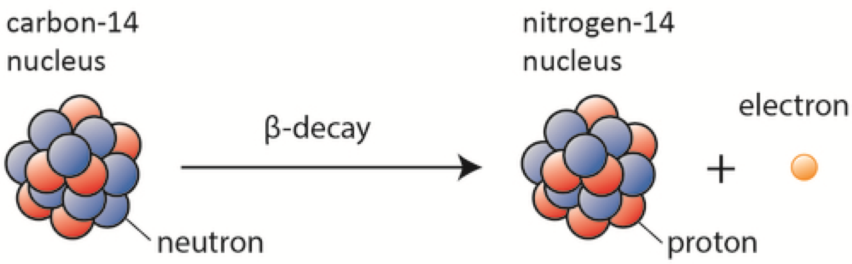
By Adrian Cho | Apr. 6, 2017 , 5:30 PM

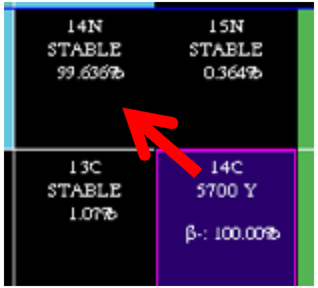
Sterile neutrino search hits roadblock at reactors

By Kathryn Jepsen

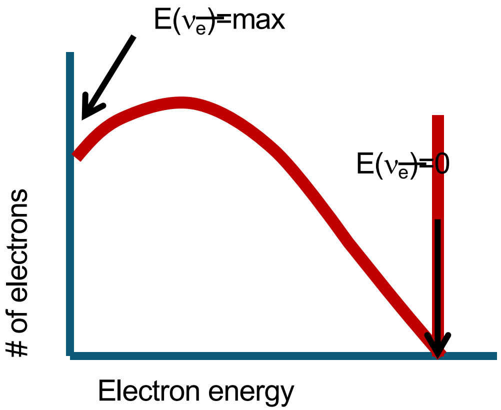
A new result from the Daya Bay collaboration reveals both limitations and strengths of experiments studying antineutrinos at nuclear reactors.

The Neutrino Hypothesis (1930's)





$$n \longrightarrow p + e^{-} + \bar{\nu}_e$$



Energy conservation:
Electron Energy = Mass (i) – Mass (f)

Observation:
Electron Energy = Continuous

(4 December 1930, Zürich)

Dear radioactive ladies and gentlemen:

...I have hit upon a desperate remedy to save the "exchange theorem" and the energy theorem. Namely [there is] the possibility that there could exist in the nuclei electrically neutral particles that I wish to call neutrons...

The ghost particle

Antineutrinos are produced in beta decay

$$n \rightarrow p + e^{-} + \bar{\nu}$$

How do you measure something with no electrical charge interacting only through weak interaction?

Bethe-Peierls (1934) – detection through **inverse beta decay**

$$\bar{\nu} + p \rightarrow n + e^{+}$$

The problem: cross section for reaction is ~10^{-44} cm^2 !!!

That's 10^{-20} barns !!!

The chances of a neutrino actually hitting something as it travels through all this howling emptiness are roughly comparable to that of dropping a ball bearing at random from a cruising 747 and hitting, say, an egg sandwich"

Average distance travelled in lead brick

1 light year

-- Hitchhiker's Guide to the Galaxy

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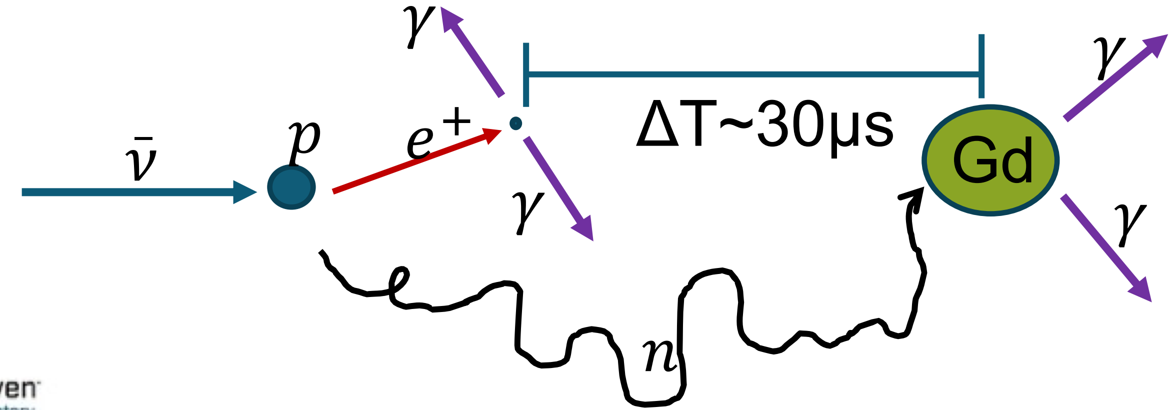
Ghostbusting with Probability

How to detect the ghost particle ?

Intense source of neutrinos × Really big detector

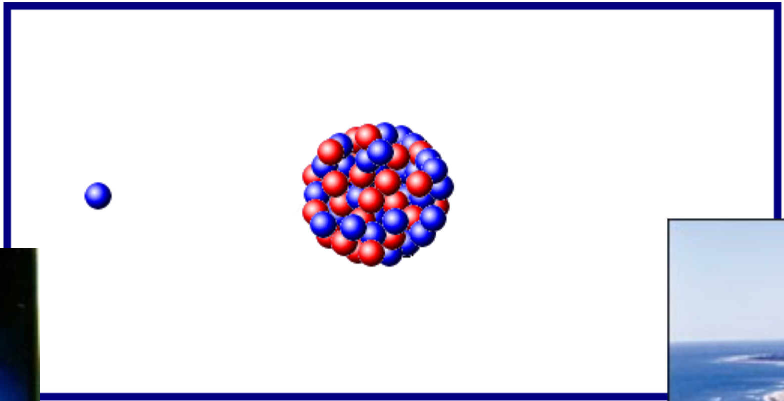
And some nuclear physics !

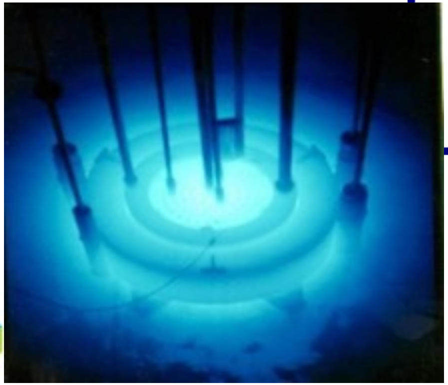
$$\bar{\nu} + p \rightarrow n + e^{+}$$



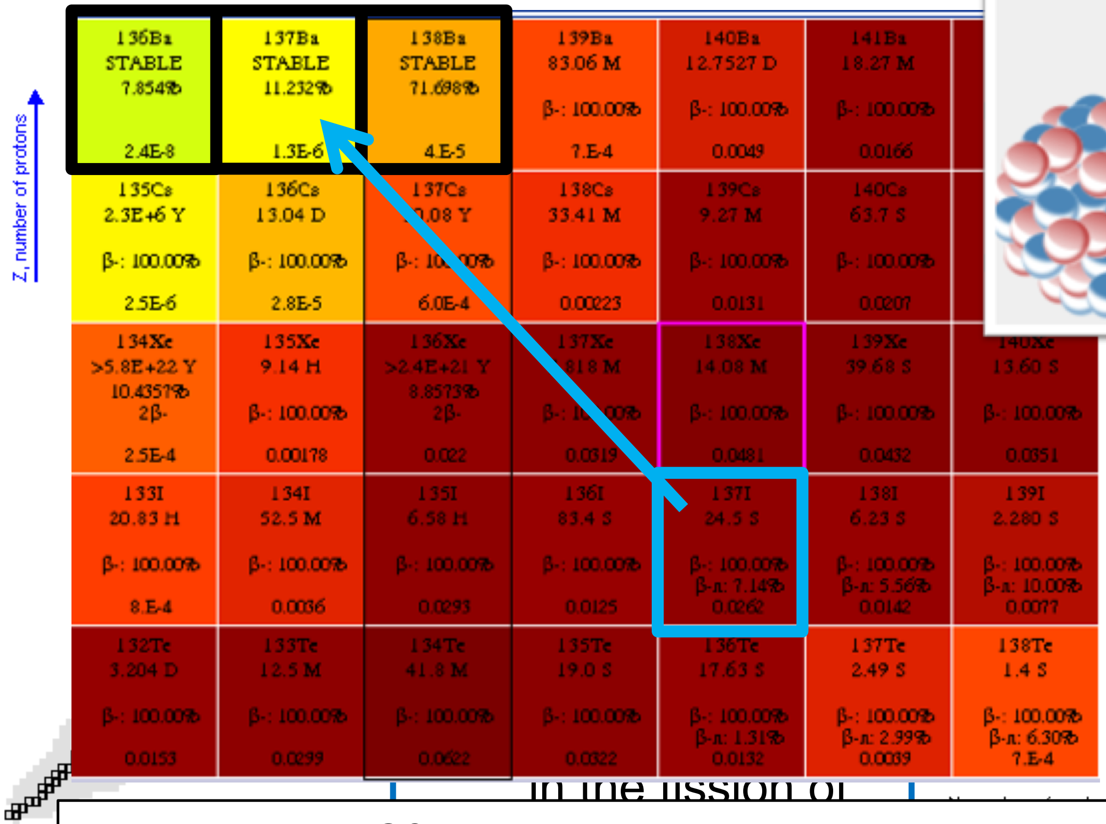
Nuclear Physics Powering a Reactor

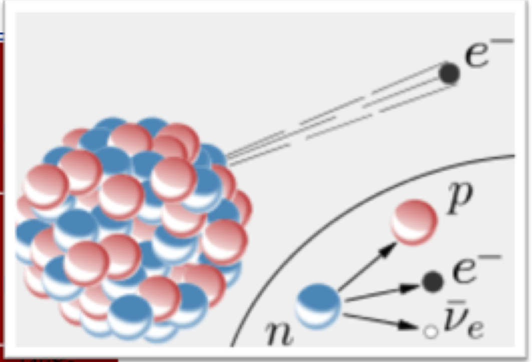
- Fissile material, such as uranium or plutonium
- Neutrons are used to induce fission
- Products of fission : 2 lighter nuclei and a few neutrons
- New neutrons carry on, and on, and on the process





Yields of Fission Fragments





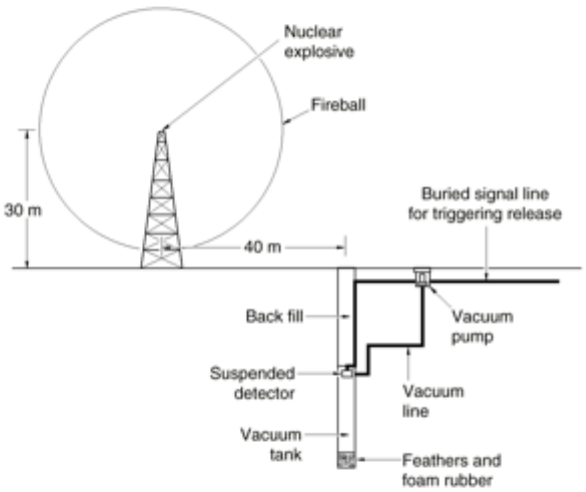
Flux ~ 10^{20} antineutrinos / s

The Neutrino Discovery (1953)

Cowan and Reines:

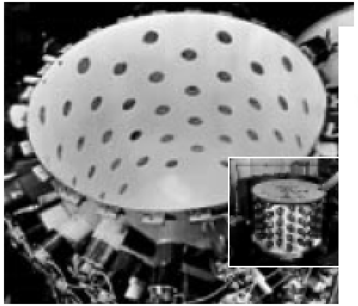
1995 Nobel Prize for detection of the neutrino

Outside the Box thinking



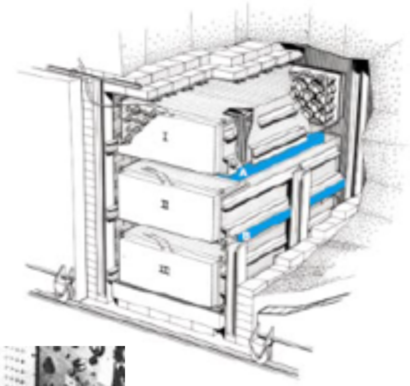
Approved at Los Alamos

A saner approach : Nuclear Reactor



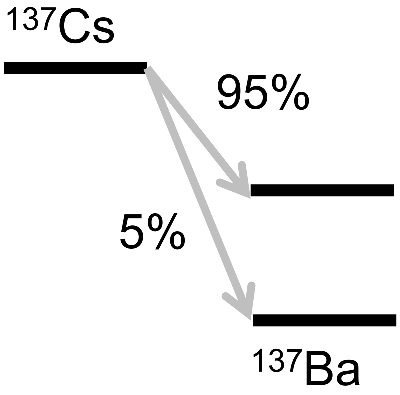
The Hanford Neutrino Detector

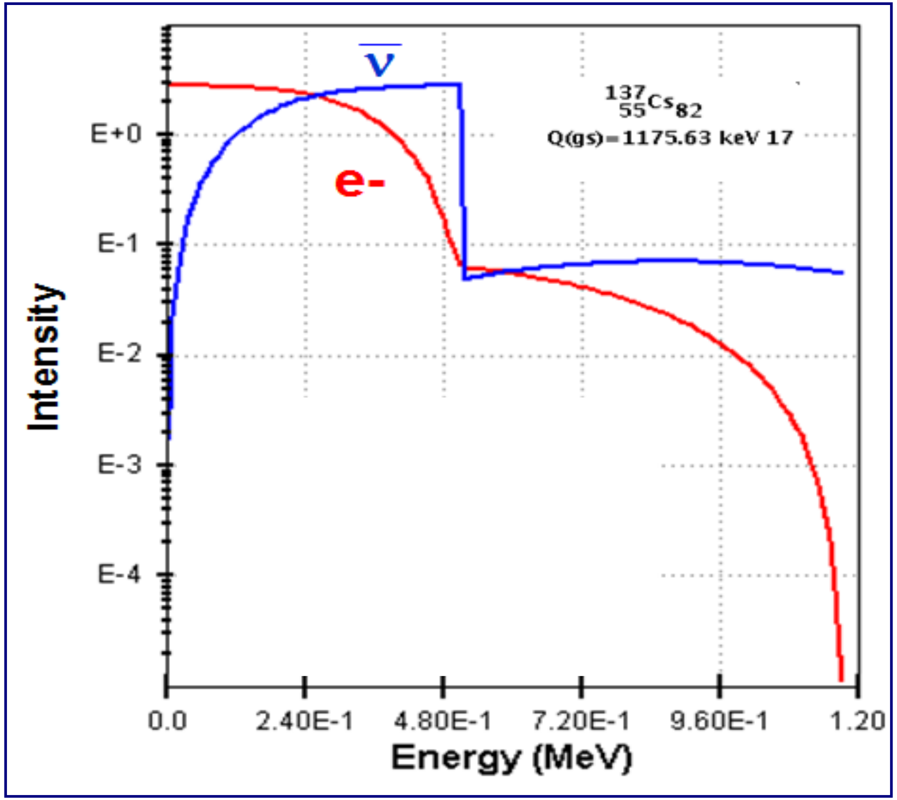
Savannah River



Fred Reines Clyde Cowan

Simple Example : ^{137}Cs





Brookha
National Labo

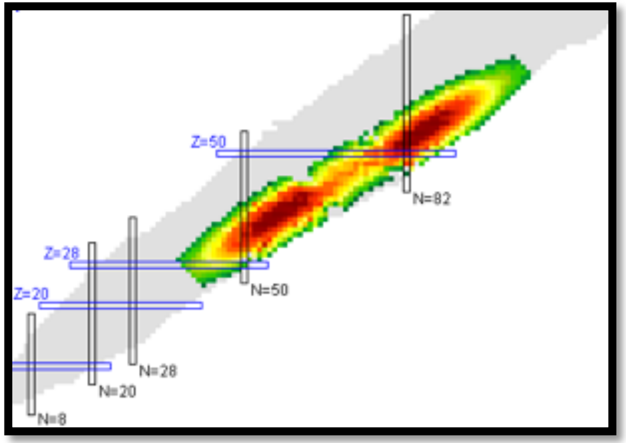
$$S(E)=N\,W\,(W^2-1)^{1/2}(W-W_0)^2\,F(Z,W)\,C(Z,W)(1+\delta)$$

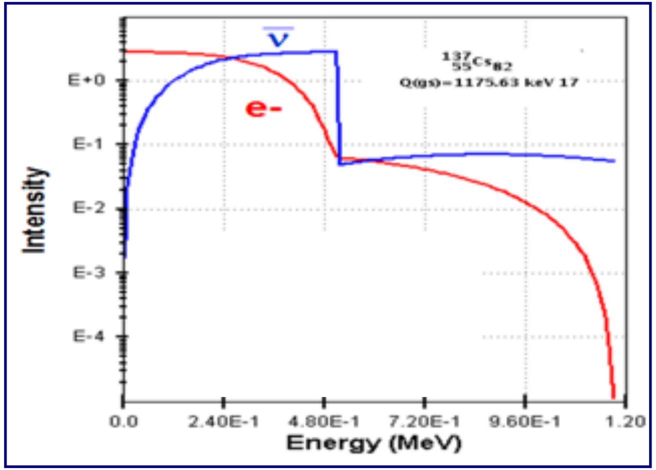
The Summation Method

$$S(E) = \sum CFY_i S_i(E)$$

Cumulative Fission Yields

Individual Spectra

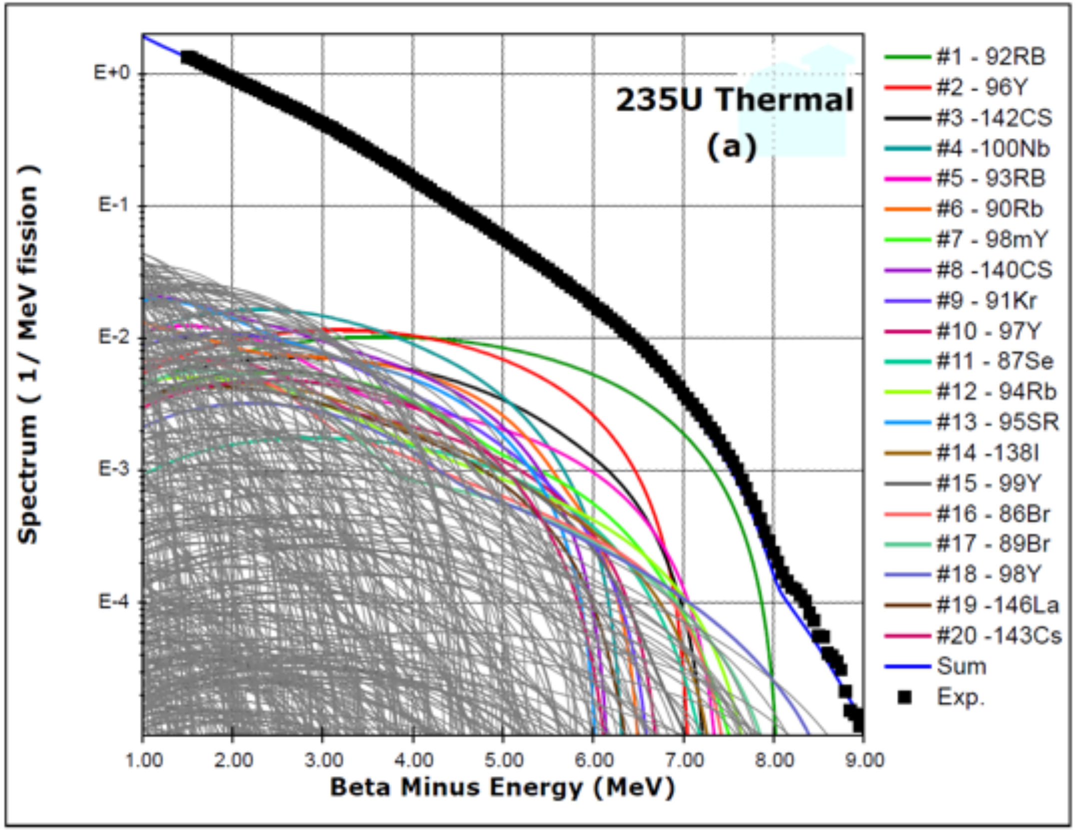




Low precision (~10 % uncertainty) but …

- Can calculate for any fissioning isotope
- Has direct link to underlying physics
- Doesn't rely on a single measurement

Summation Calculations for ^{235}U



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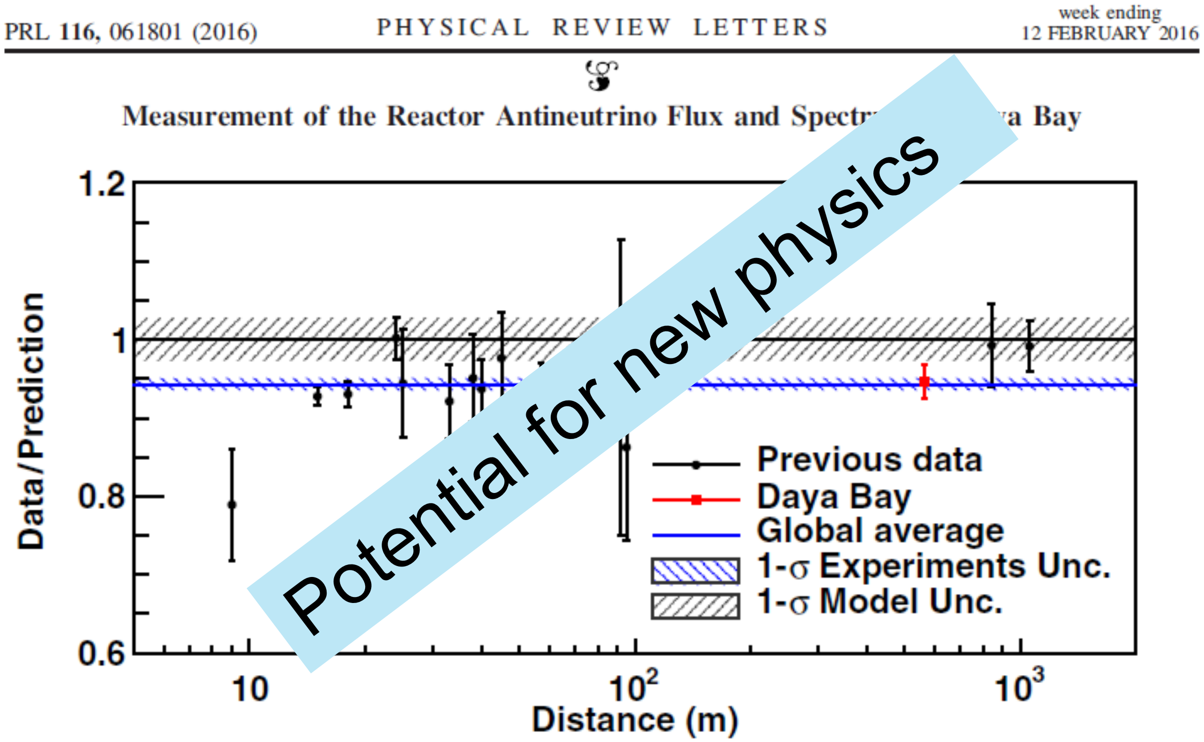
A.A. Sonzogni, T.D. Johnson, E.A. McCutchan, Phys. Rev. C 91, 011301(R) (2015).

Reactor Antineutrino Anomaly

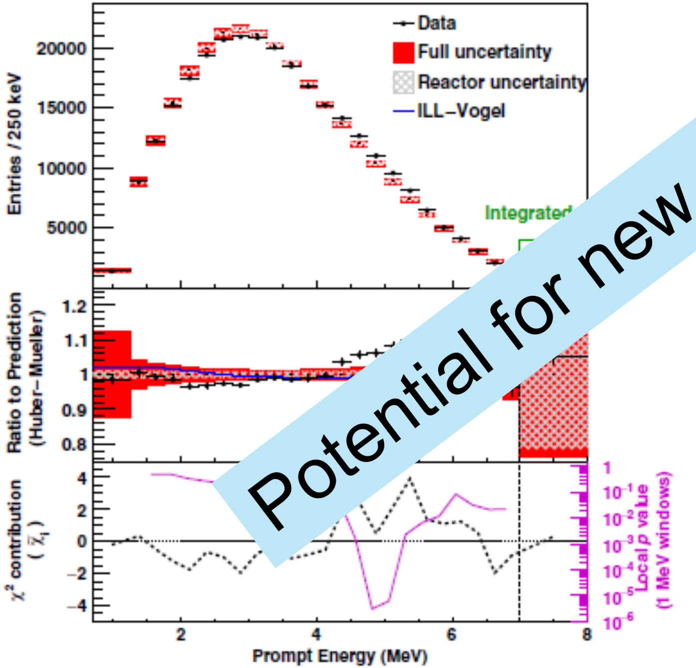


Data/prediction = 0.946+-0.022

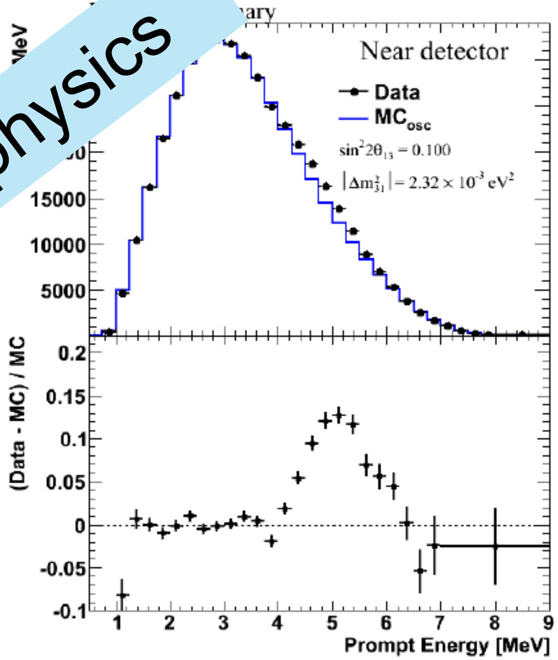
And more interesting

The "**bump**" :

An excess of measured antineutrinos relative to predictions

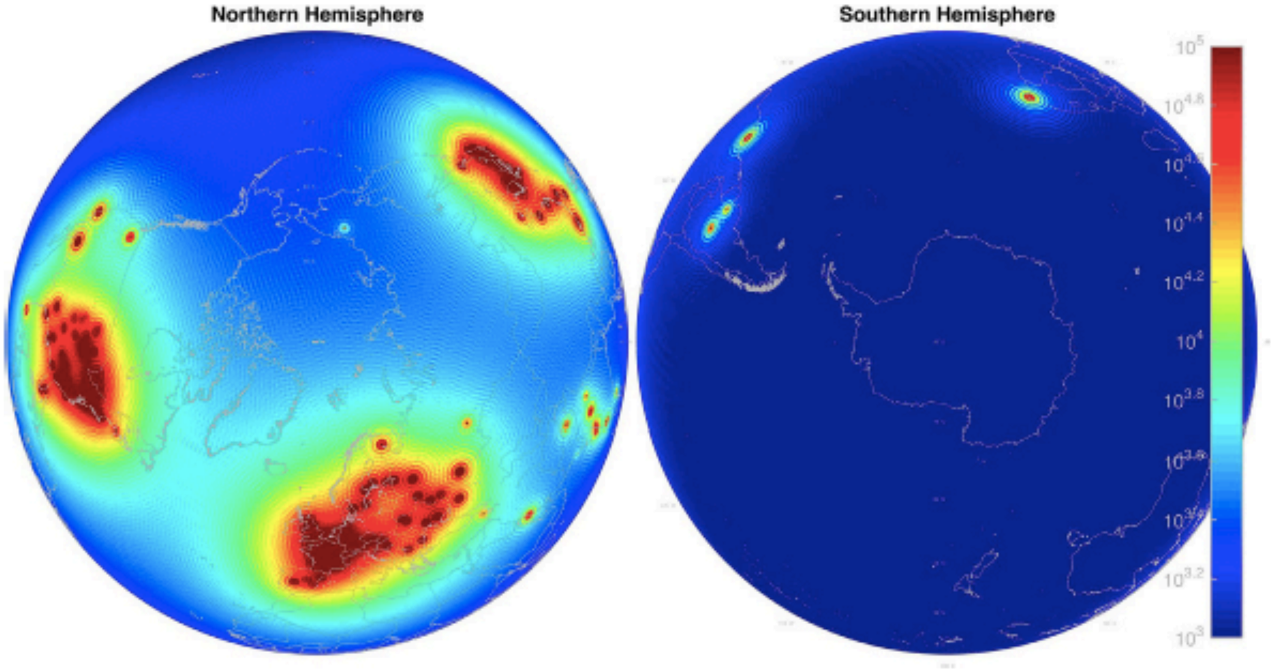


Potential for new physics



F.P. An *et al*, Phys. Rev. Lett. **116**, 061801 (2016)

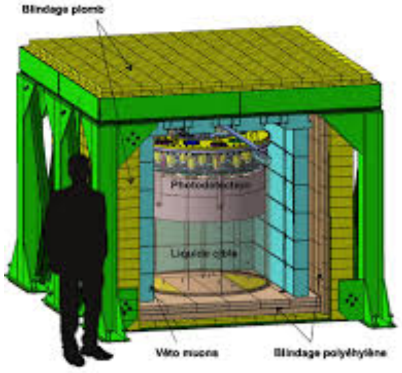
Back to Nuclear Power

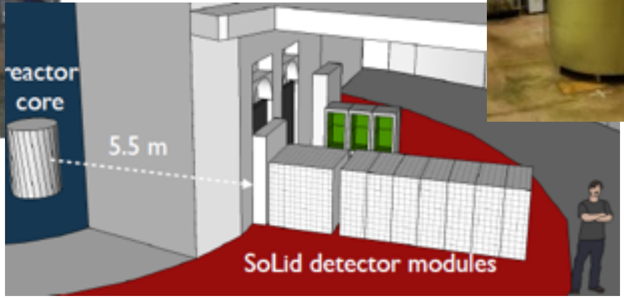


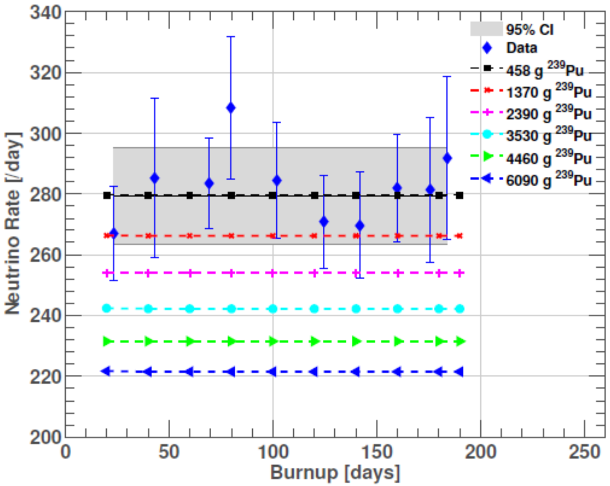
AGM reactor flux at Earths surface – Nature 2015

Inextricable link – 238U can be converted to 239Pu in a reactor

Active and exciting developments worldwide



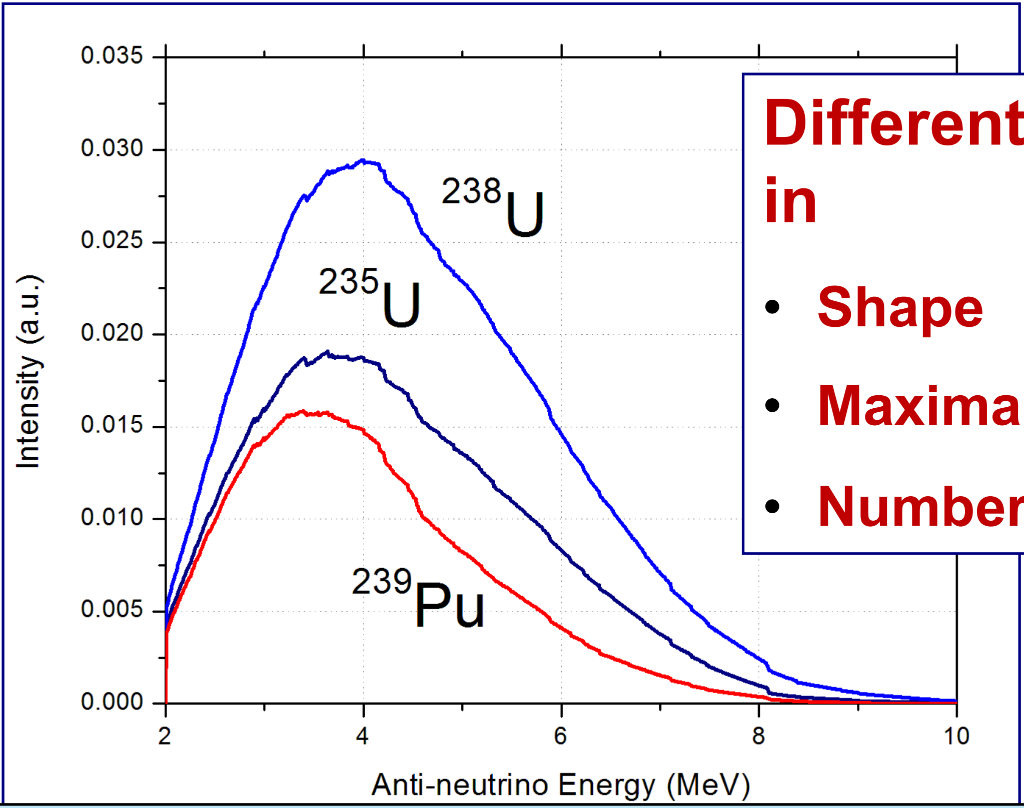




Many efforts

- USA
- Canada
- Japan
- France
- Brazil
- Italy
- UK
- Korea

Exploit differences in signal



Different signal in

- **Shape**
- **Maxima**
- **Number**

Can be used in non-proliferation and reactor monitoring
Advantages : Non-intrusive, “real-time” measurements

Watchman experiment

The New York Times

How to Spot a Nuclear Bomb Program? Look for Ghostly Particles

The Boulby mine in northeast England will be home to the Watchman experiment, which aims to

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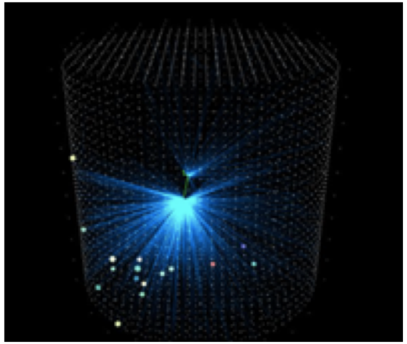
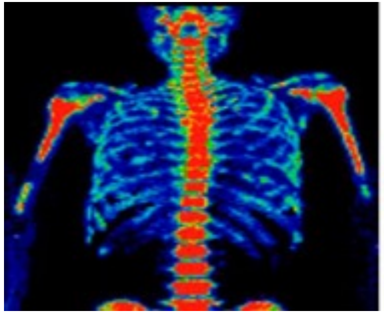


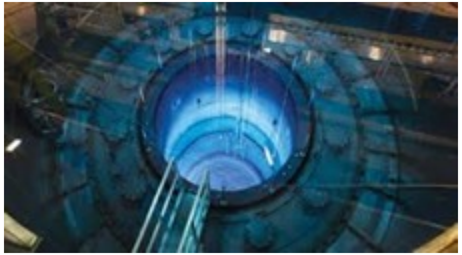
- Collaboration between UK and USA
- Demonstrate sensitivity to fuel at 10’s of k distance
- First results expected 2024

Applications of Nuclear Data



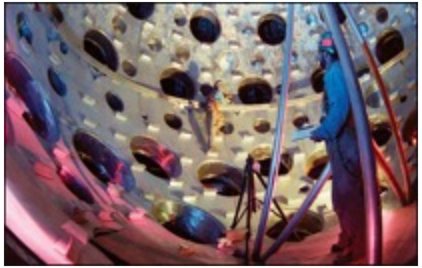
Nuclear Medicine

How can I produce and use radioactive isotopes in the body?



Nuclear Power

Is there new physics beyond the standard model and can we make the world safer?



Stockpile Stewardship

How do you ensure something will work after decades on the shelf?

Homeland Security

Space Exploration

How do I determine what's in something I can't see or touch?

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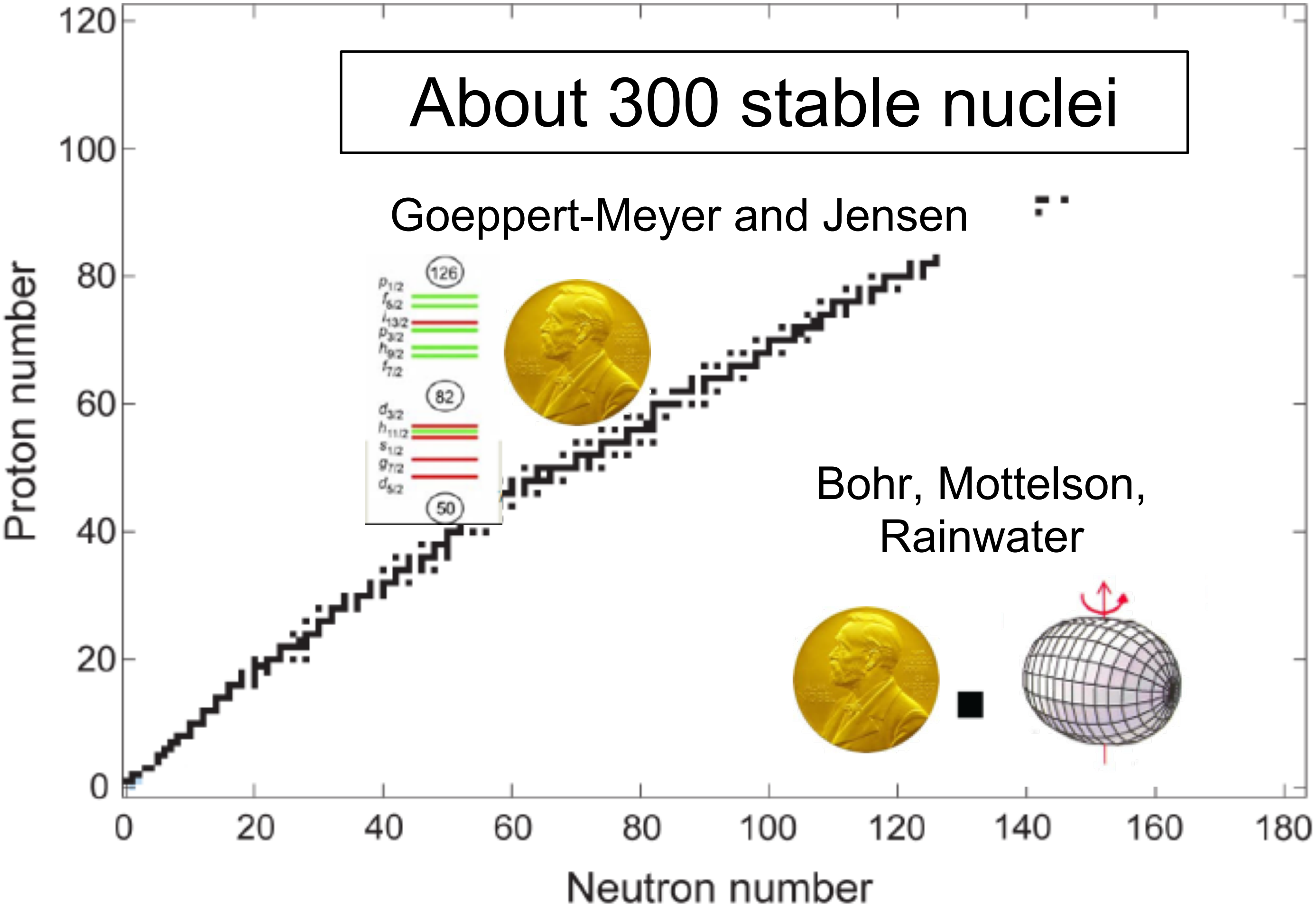
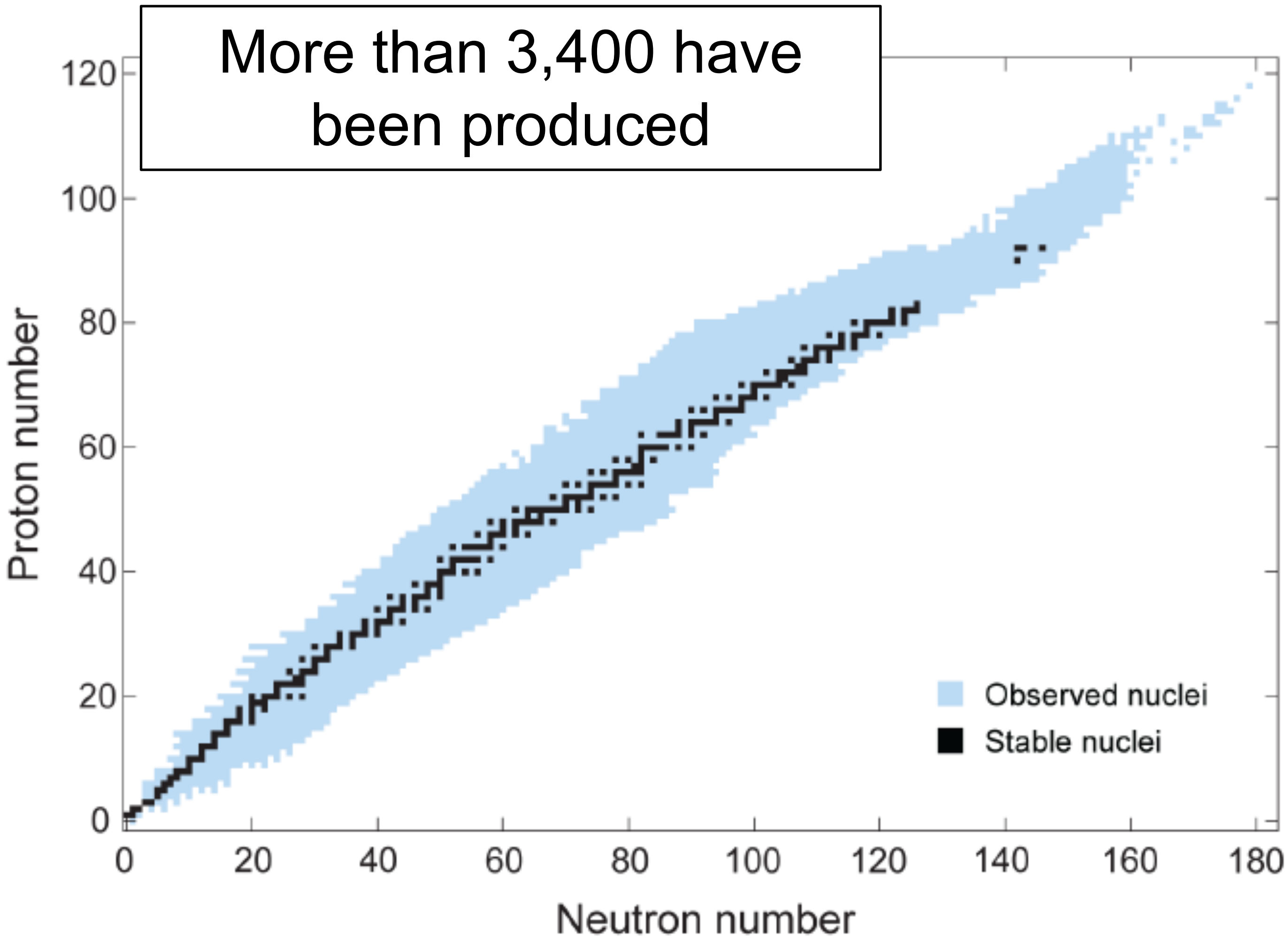
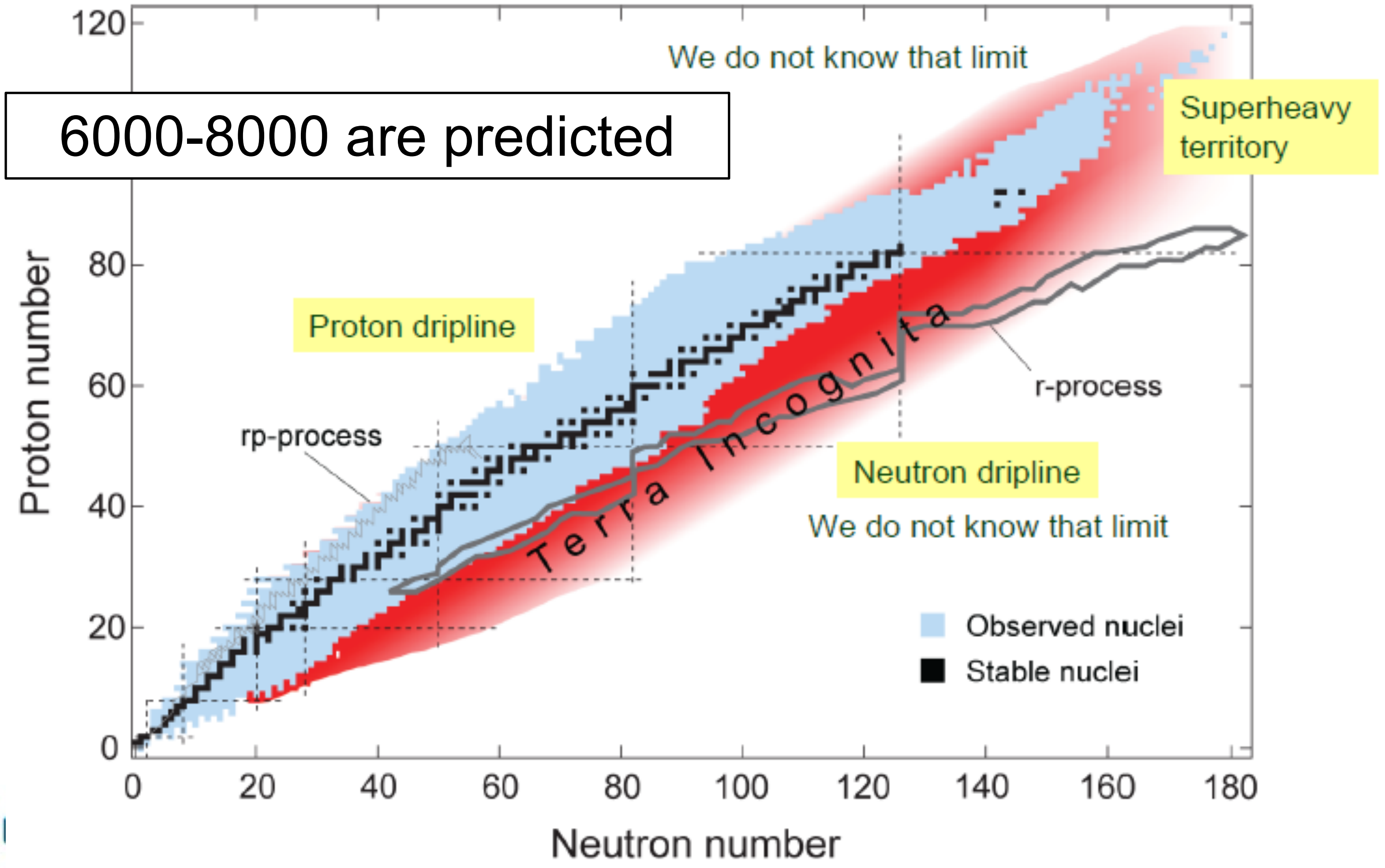

About 300 stable nuclei
Goeppert-Meyer and Jensen
Bohr, Mottelson,
Rainwater
126
p1/2
f5/2
i13/2
p3/2
h9/2
f7/2
82
d3/2
h11/2
s1/2
g7/2
d5/2
50
Proton number
Neutron number
0
20
40
60
80
100
120
140
160
180


More than 3,400 have been produced
Proton number
Neutron number
Observed nuclei
Stable nuclei
0
20
40
60
80
100
120
140
160
180

6000-8000 are predicted



Take away message

Main thing to take away from this talk

- We work for YOU!!
- Comments/suggestions/criticisms are welcome
- You (should) shape the future of nuclear data