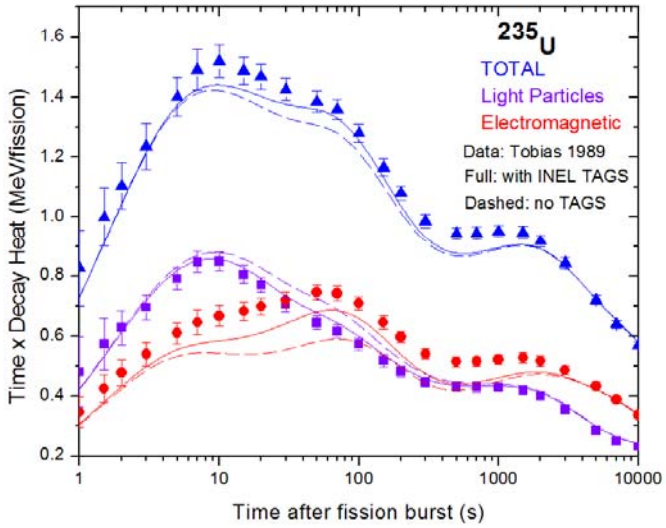
Beta-Decay Studies of Neutron-Rich Fission Products for Advanced Fuel Cycle Applications

ARRA Grant KB-04-01-02-2 FWP#22930



C.J. (Kim) Lister (ANL Physics), P. Chowdhury (U. Mass Lowell), F. Kondev (ANL Nuclear Engineering).
R. Vondrasek, R. Pardo, G. Savard, P. Bertone, C. Nair, A. Deo, L. SoundaraPandian, S. Zhu

SC_ANST Exchange meeting 20-21st August 2011

Plan of Talk:

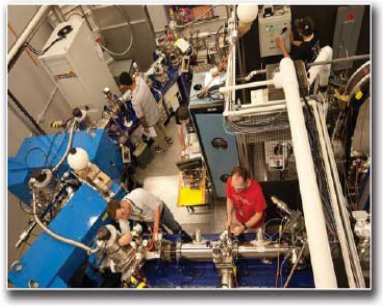
- Science Opportunities
- CARIBU
  - First Decay Data
  - First Accelerated Beams
- Tools
  - The Decay Beam line
  - Data Acquisition
  - Tape Stations
  - X-Array
  - Calorimetry.
- Status

Decay Workshop

Workshop on "Decay Spectroscopy at CARIBU: Advanced Fuel Cycle Applications, Nuclear Structure and Astrophysics"

April 14-16, 2011 at

Argonne NATIONAL LABORATORY

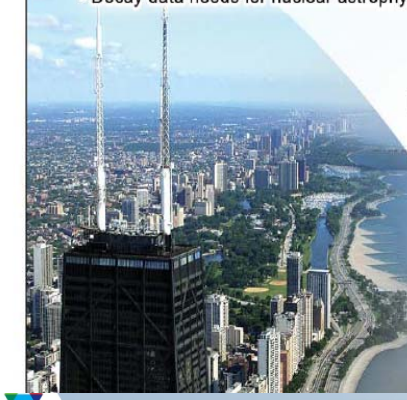


A workshop on "Decay Spectroscopy at CARIBU: Advanced Fuel Cycle Applications, Nuclear Structure and Astrophysics" will be held at Argonne National Laboratory on April 14-16, 2011.

The aim of the workshop is to discuss opportunities for decay studies at the Californium Rare Isotope Breeder Upgrade (CARIBU) of the ATLAS facility with emphasis on advanced fuel cycle (AFC) applications, nuclear structure and astrophysics research. The workshop will consist of review and contributed talks. Presentations by members of the local groups, outlining the status of relevant in-house projects and available equipment, will also be organized. Time will also be set aside to discuss and develop working collaborations for future decay studies at CARIBU.

Topics of interest include:

- Decay data of relevance to AFC applications with emphasis on reactor decay heat
- Discrete high-resolution gamma-ray spectroscopy following radioactive decay and related topics
- Calorimetric studies of neutron-rich fission fragments using Total Absorption Gamma-ray Spectrometry (TAGS) technique
- Beta-delayed neutron emissions and related topics
- Decay data needs for nuclear astrophysics



Workshop Organizers

Dr. Michael Carpenter, Argonne National Laboratory
Prof. Partha Chowdhury, University of Massachusetts Lowell
Dr. Jason Clark, Argonne National Laboratory
Dr. Filip Kondev, Argonne National Laboratory
Dr. Kim Lister, Argonne National Laboratory
Dr. Dariusz Seweryniak, Argonne National Laboratory

Please visit the Workshop web site for additional information about registration, program, lodging and transportation to Argonne.

http://www.pe.anl.gov/capabilities/nd/AFC-Apr11/

14-16th April 2011

79 Participants from 13 countries and 28 institutions

Aimed at engaging the community in CARIBU decay (and accelerated beam) physics.

Decay Heat
Astrophysics
Nuclear Structure

Three Areas of Opportunity

Astrophysics

R-process nuclei: There is a compelling case for measuring masses and half-lives of accessible neutron-rich nuclei, as these quantities strongly influence the process path, its flow, and resulting abundances.

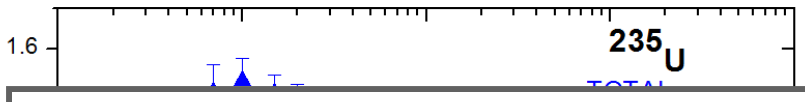
Structure

Neutron rich nuclei: There is a good case for carefully examining the accessible neutron-rich nuclides and understanding structural features caused by large neutron excesses and poor binding.

Applications (Advanced Fuel Cycles)

Decay Heat and Neutrons: It becomes increasingly clear that for fission products from “minor actinides” the decay data is poor and incomplete. CARIBU is the perfect instrument for improving this situation. Key areas: Absolute decay strength functions, neutrons, correlated errors.

Decay heat profiles are still difficult to reproduce accurately, presumably due to



Time x Decay Heat (MeV/fission)

Decay Heat t x f(t) (MeV/fission)

Selected for a Viewpoint in *Physics*

PRL **105,** 202501 (2010) PHYSICAL REVIEW LETTERS week ending 12 NOVEMBER 2010

Reactor Decay Heat in ^{239}Pu: Solving the γ Discrepancy in the 4–3000-s Cooling Period

A. Algora,[1,2,*] D. Jordan,[1] J. L. Taín,[1] B. Rubio,[1] J. Agramunt,[1] A. B. Perez-Cerdan,[1] F. Molina,[1] L. Caballero,[1] E. Nácher,[1] A. Krasznahorkay,[2] M. D. Hunyadi,[2] J. Gulyás,[2] A. Vitéz,[2] M. Csatlós,[2] L. Csige,[2] J. Äysto,[3] H. Penttilä,[3] I. D. Moore,[3] T. Eronen,[3] A. Jokinen,[3] A. Nieminen,[3] J. Hakala,[3] P. Karvonen,[3] A. Kankainen,[3] A. Saastamoinen,[3] J. Rissanen,[3] T. Kessler,[3] C. Weber,[3] J. Ronkainen,[3] S. Rahaman,[3] V. Elomaa,[3] S. Rinta-Antila,[3] U. Hager,[3] T. Sonoda,[3] K. Burkard,[4] W. Hüller,[4] L. Batist,[5] W. Gelletly,[6] A. L. Nichols,[6] T. Yoshida,[7] A. A. Sonzogni,[8] and K. Peräjärvi[9]

[1]*IFIC (CSIC-Univ. Valencia), Valencia, Spain*
[2]*Institute of Nuclear Research, Debrecen, Hungary*
[3]*University of Jyväskylä, Jyväskylä, Finland*
[4]*GSI, Darmstadt, Germany*
[5]*PNPI, Gatchina, Russia*
[6]*University of Surrey, Guildford, United Kingdom*
[7]*Tokyo City University, Setagaya-ku, Tokyo, Japan*
[8]*NNDC, Brookhaven National Laboratory, Upton, New York, USA*
[9]*STUK, Helsinki, Finland*

(Received 13 May 2010; published 8 November 2010)

The β feeding probability of ^{102,104,105,106,107}Tc, ^{105}Mo, and ^{101}Nb nuclei, which are important contributors to the decay heat in nuclear reactors, has been measured using the total absorption technique. We have coupled for the first time a total absorption spectrometer to a Penning trap in order to obtain sources of very high isobaric purity. Our results solve a significant part of a long-standing discrepancy in the γ component of the decay heat for ^{239}Pu in the 4–3000 s range.

Fig.39 Gamma-ray discrepancies seen in ^{239}Pu decay heat after a fission burst (Yoshida et al, 1999).

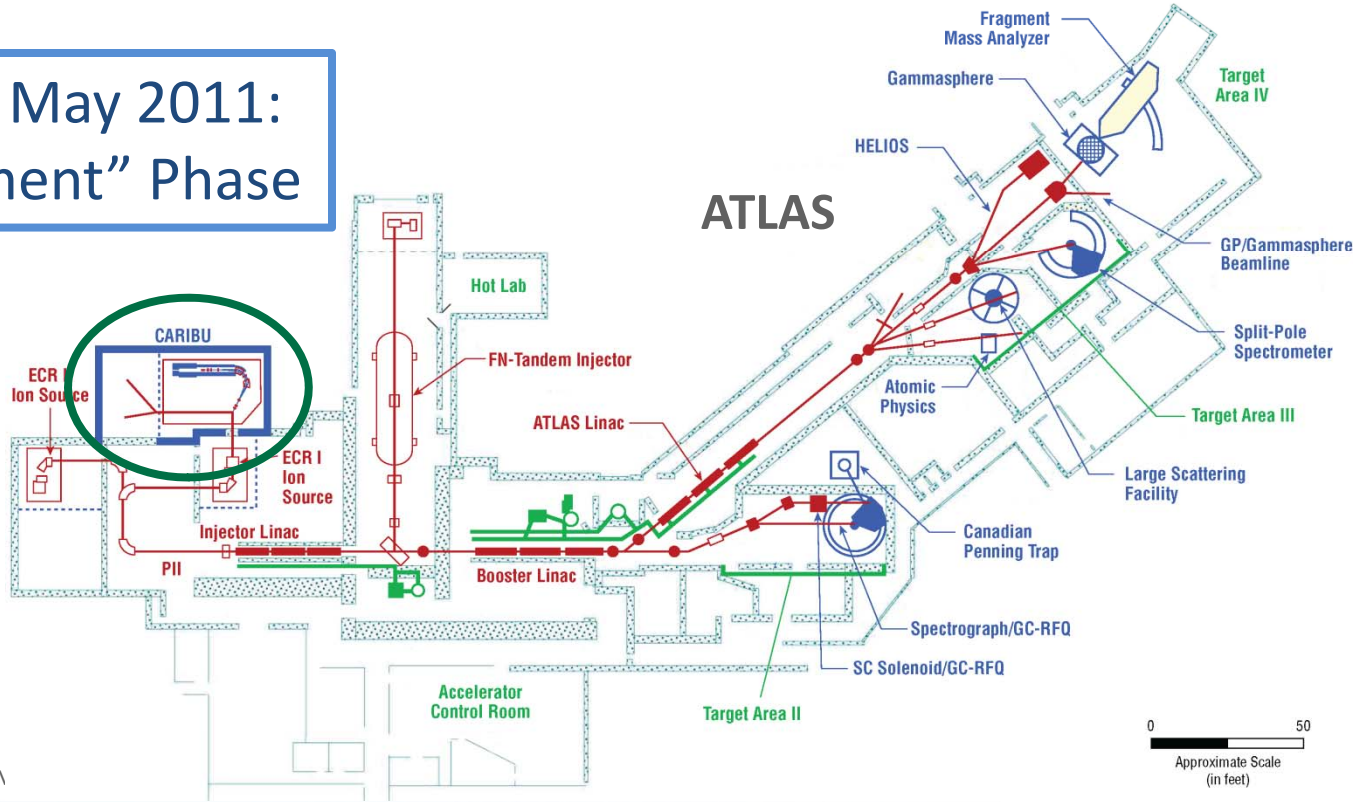
54-Xe-139	1	5057 (21)	39.68 s	9.4E+06	6.9E+05
54-Xe-140	1	4060 (60)	13.6 s	6.9E+06	5.0E+05
55-Cs-142	?	7308 (11)	1.69 s	6.8E+06	2.5E+05
56-Ba-145	2	5570 (110)	4.31 s	5.5E+06	2.0E+05
57-La-143	2	3425 (15)	14.2 min	2.8E+06	1.0E+05
57-La-145	2	4110 (80)	24.8 s	6.8E+06	2.5E+05

CARIBU – Californium Rare Ion Breeder Upgrade

Use 1Ci of ^{252}Cf ($T_{1/2}$=2.645y, $Br_{(f)}$ = 3.09%) to produce neutron-rich isotopes

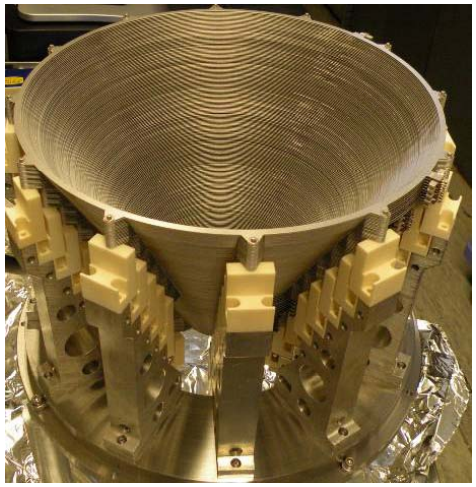
- Project goal: Provide neutron-rich radioactive beams to user community
  - Low-energy
    - Masses, decay spectroscopy, laser spectroscopy, …
  - Reaccelerated through ATLAS at up to 15 MeV/u
    - Single particle structure, gamma-ray spectroscopy, …

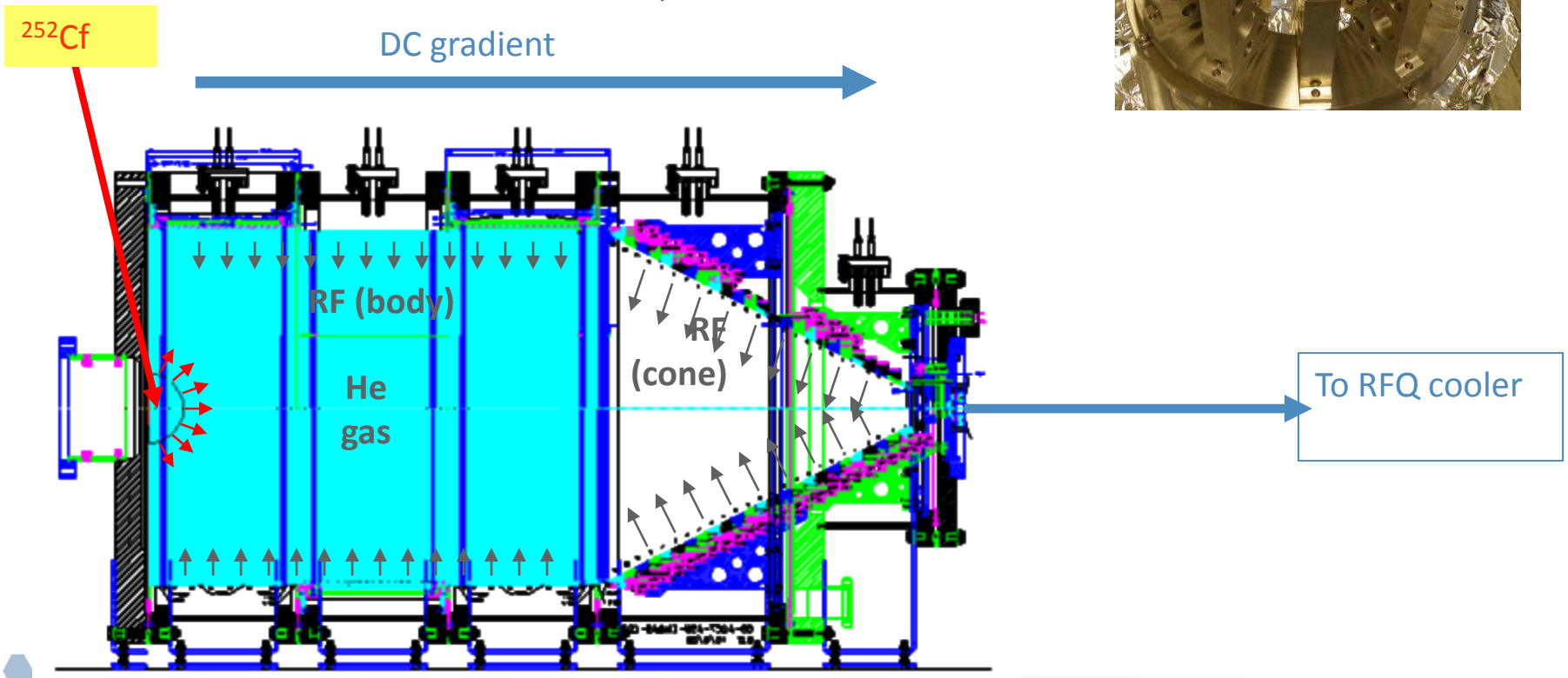
Commissioned in May 2011:
Now in "Development" Phase



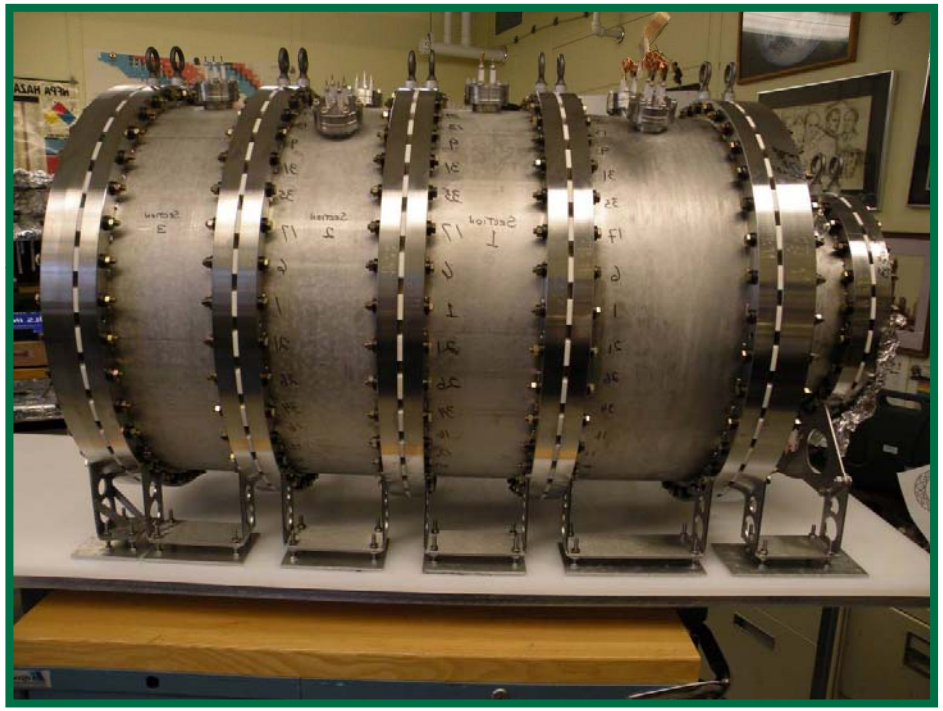
CARIBU gas catcher: transforms fission recoils into a beam with good optical properties

- Device similar to ANL RIA/FRIB gas catcher prototype
  - Radioactive ion transport by RF + DC + gas flow
  - Stainless steel and ceramics construction
  - Similar length
  - Twice the diameter (50 cm inner diameter)
  - Extraction in 2 RFQ sections with μRFQs

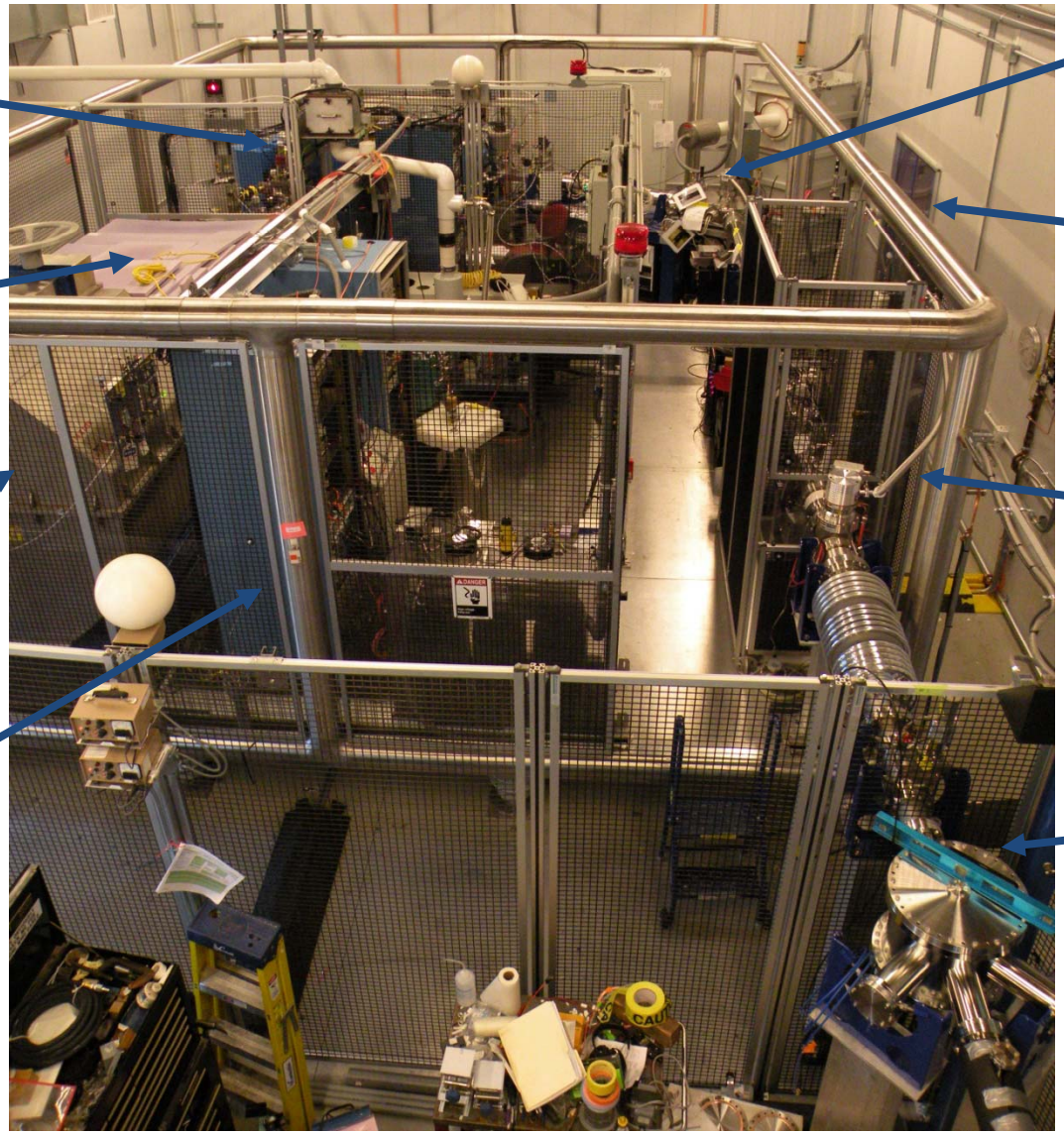




Ion extraction and beam formation: CARIBU gas catcher, RFQs and acceleration section completed and assembled

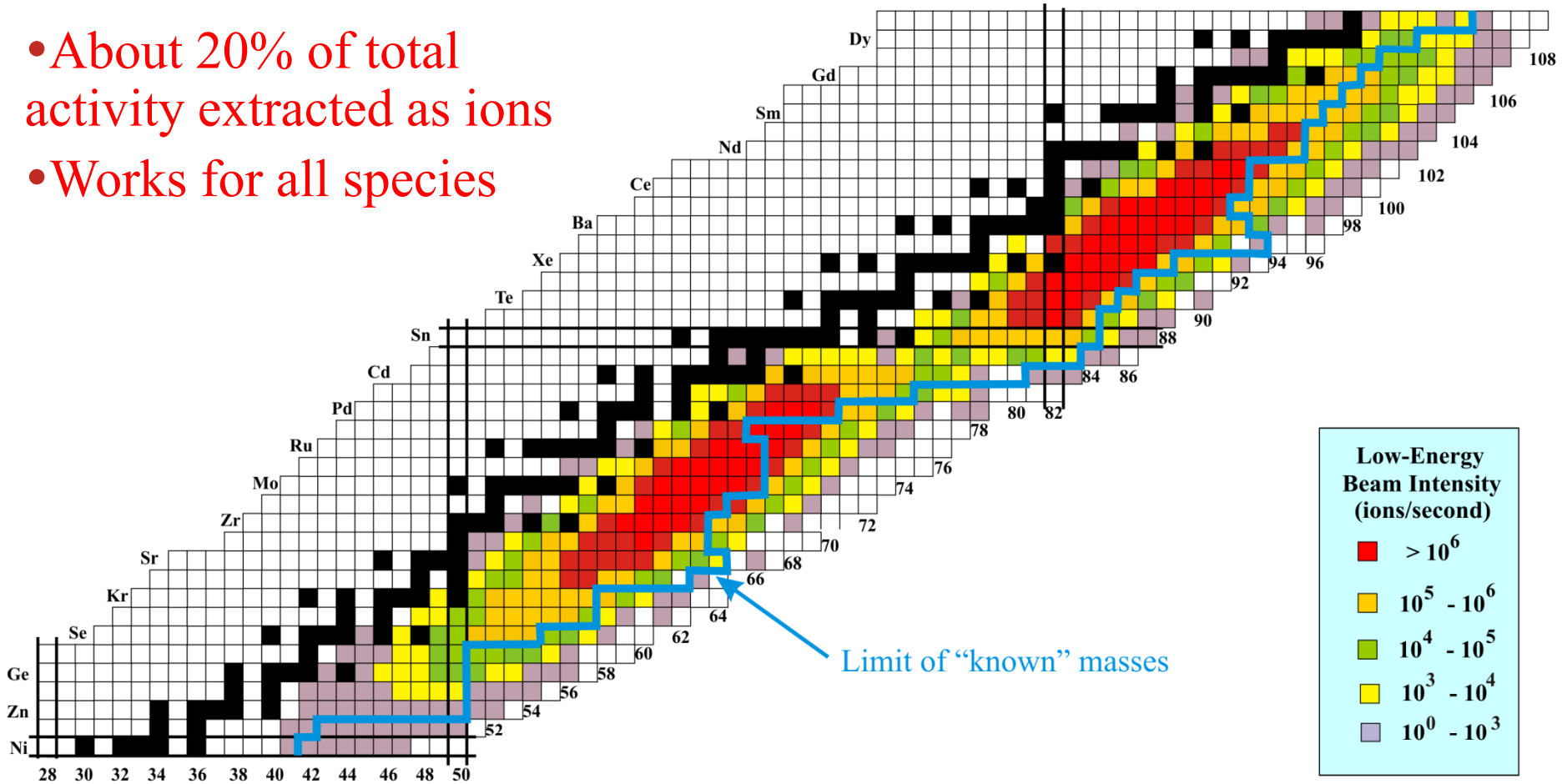


CARIBU completed

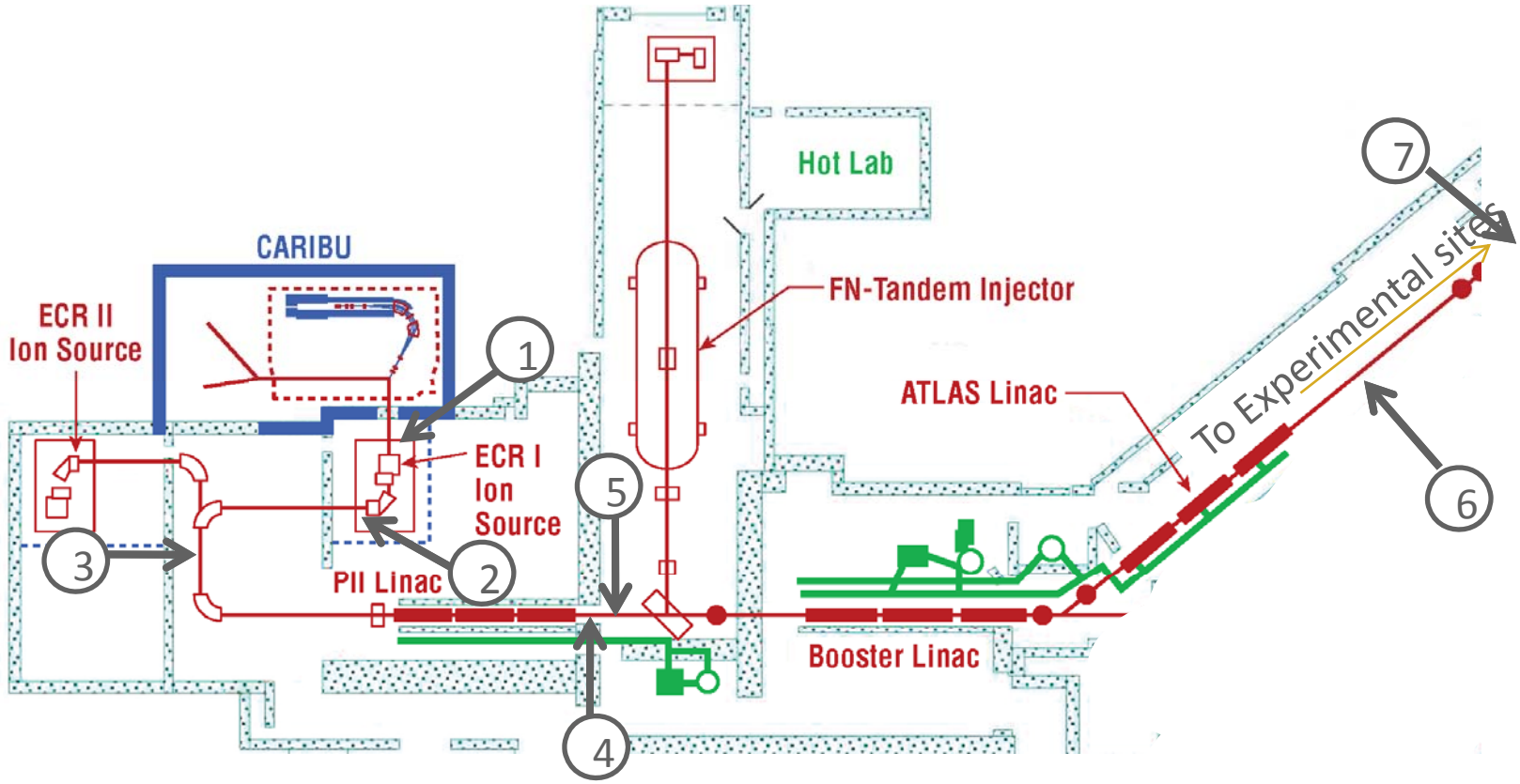


Extracted isotope yield at low energy (50 keV)

- 1 Ci ^{252}Cf source
- About 20% of total activity extracted as ions
- Works for all species



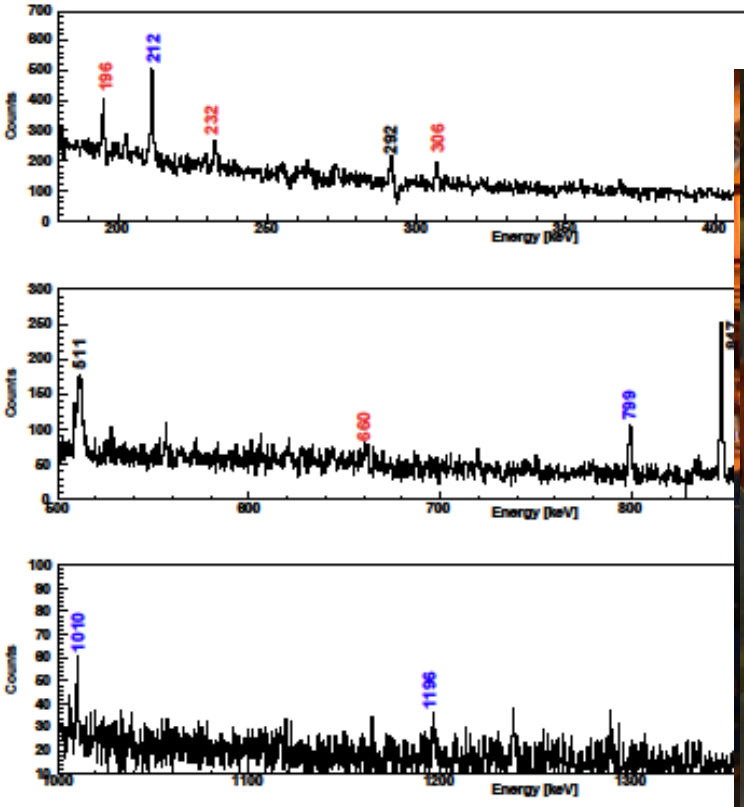
“Reference points”



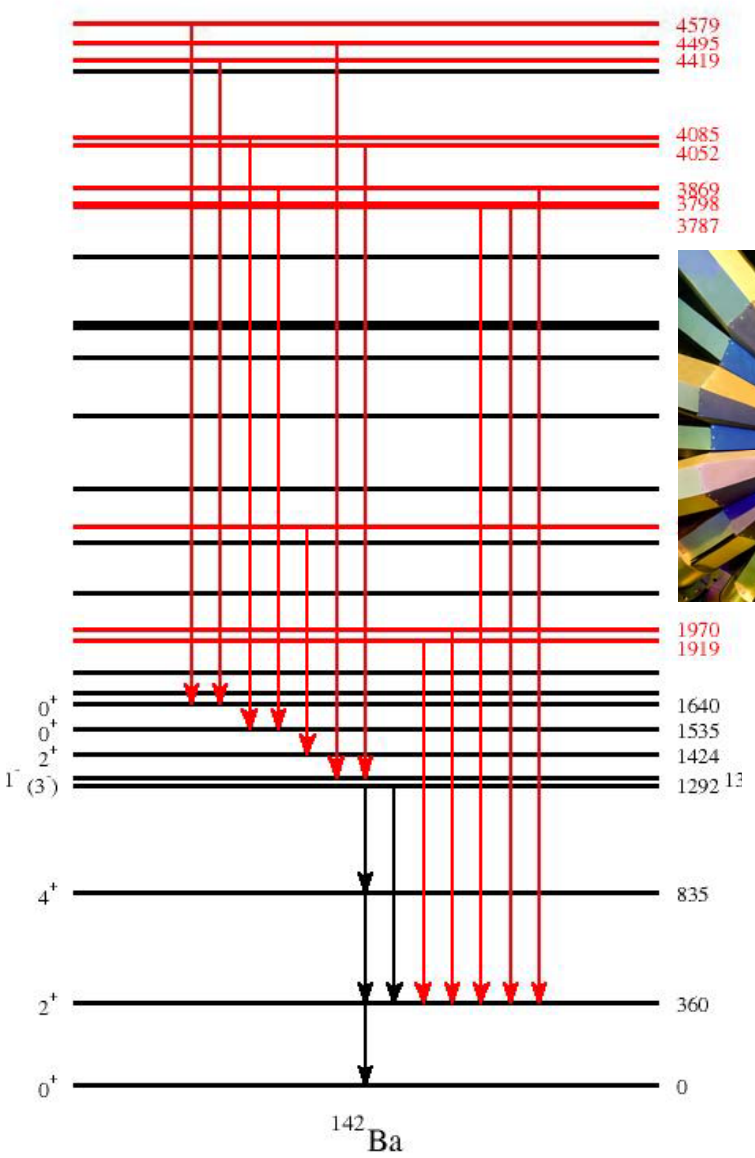
- 1- ECR entrance
- 2- ECR exit
- 3- pre-PII FCP
- 4 – PII FCP
- 5- PII exit valve
- 6- ATLAS valve
- 7-ATLAS FCP

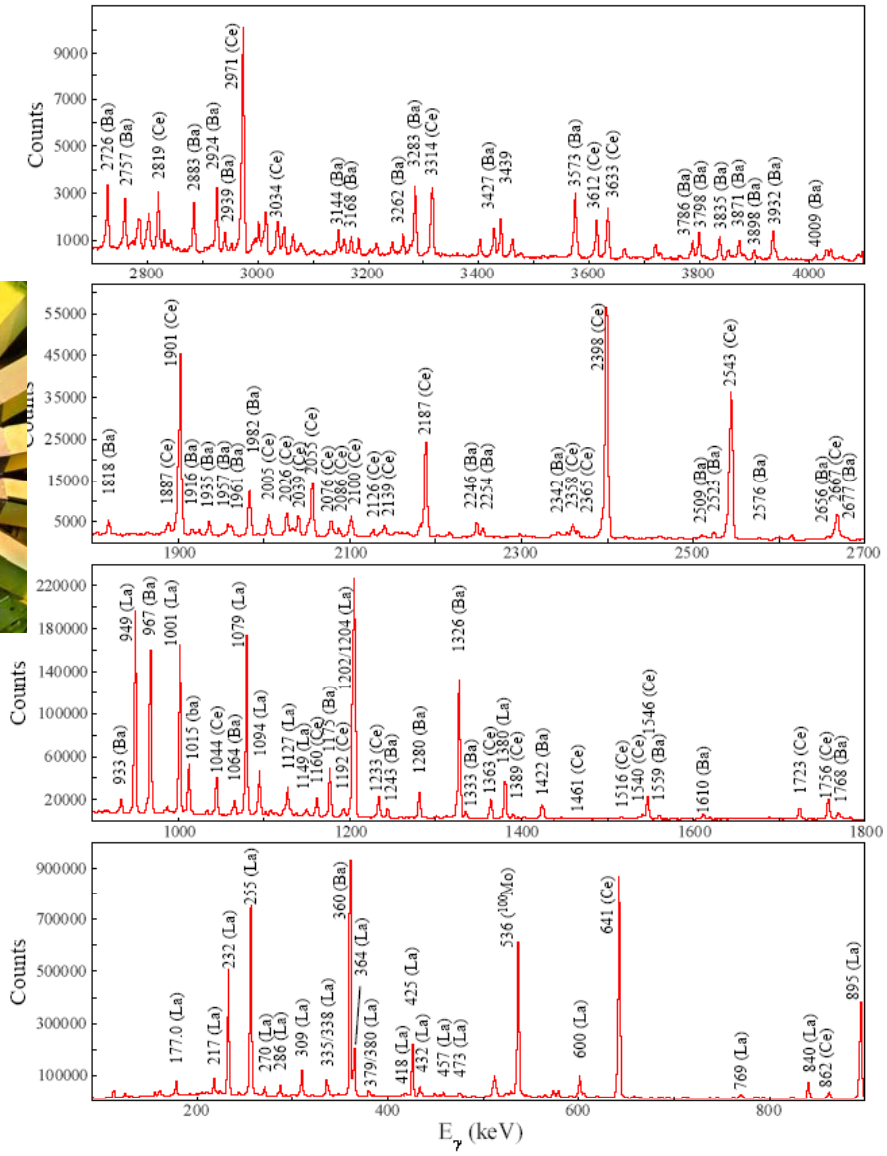
CARIBU Beam Diagnostics through ATLAS

As always with gamma rays ….. ABSOLUTE yields need careful calibration……



First decay schemes from CARIBU Ions





Data from Shaofei Zhu (PHY)

The ARRA-funded decay heat group

Three Group Collaboration:-

CJL (Argonne Physics)
Filip Kondev (Argonne Nuclear Engineering / NNDC)
Partha Chowdhury (University of Massachusetts, Lowell)

Post Docs

Peter Bertone (PHY)
Chithra Nair (NE)
Ajay Deo (Lowell)
Lakshmi SoundaraPandian (Lowell)

Student:-

Michael Smith (Australian National University)
{Supervisor Greg Lane (ANU)}

Tools

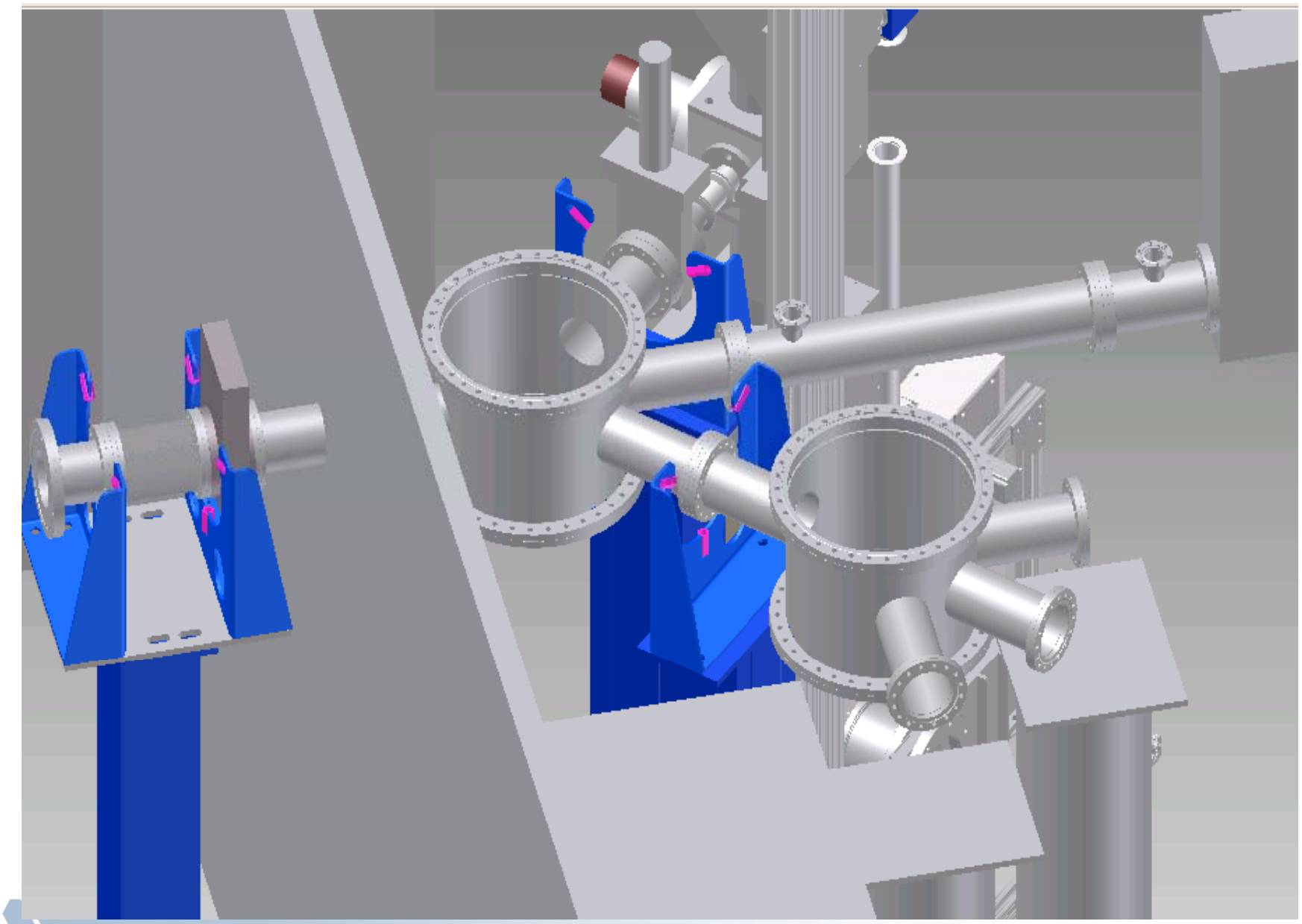
Beam line and Infrastructure

Tape Stations

X-Array

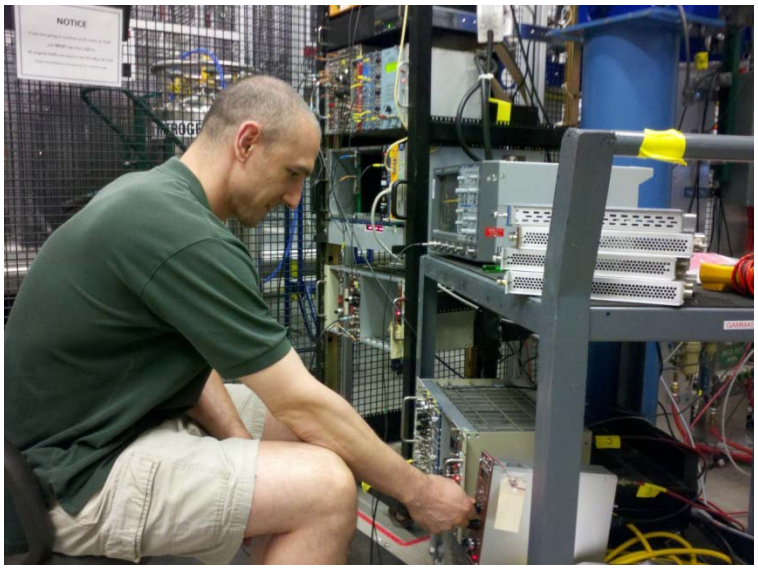
Calorimeter (TAS)

Beam line / Infrastructure



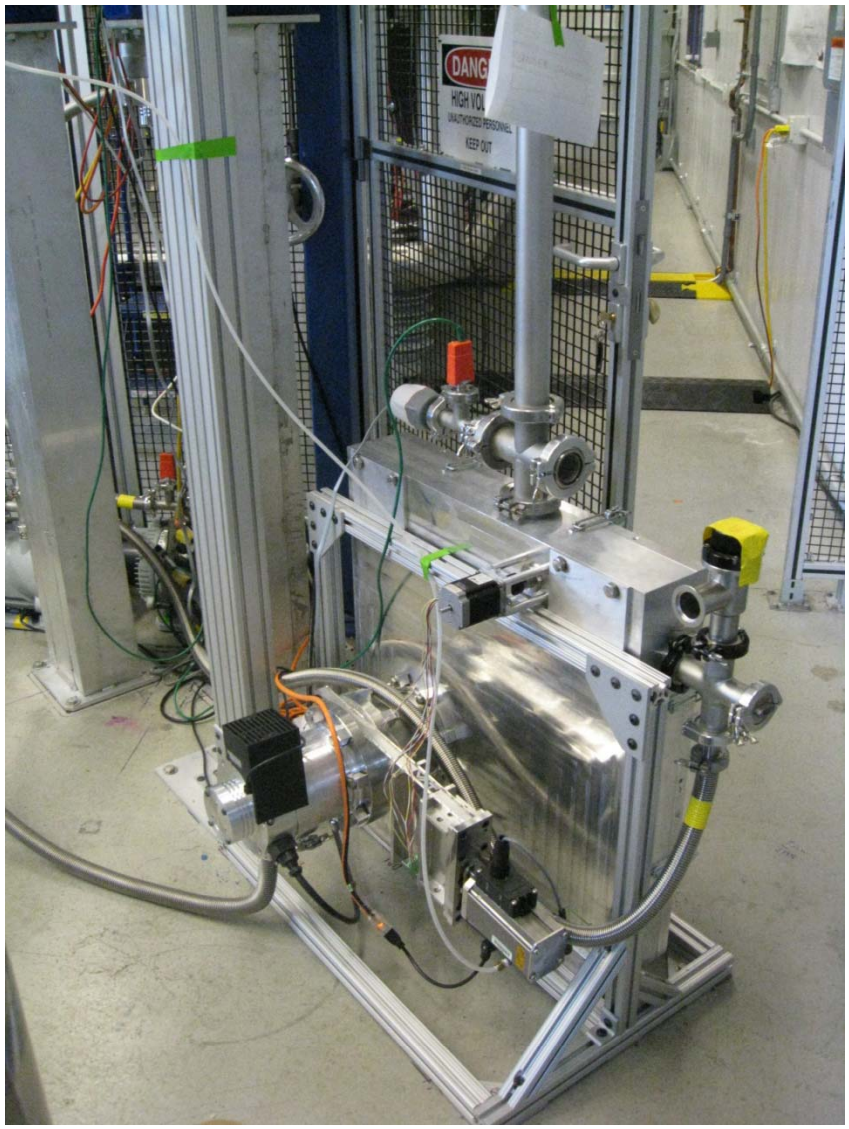
Beam line / Infrastructure

Optics
Design of switchyard
Construction
Clean Power
Beam lines
Network
Data Acquisition



Tape Transport: Status 08/2011

Construction: P. Bertone / B. DiGiovine



First tape station laboratory tested and now deployed at CARIBU:-

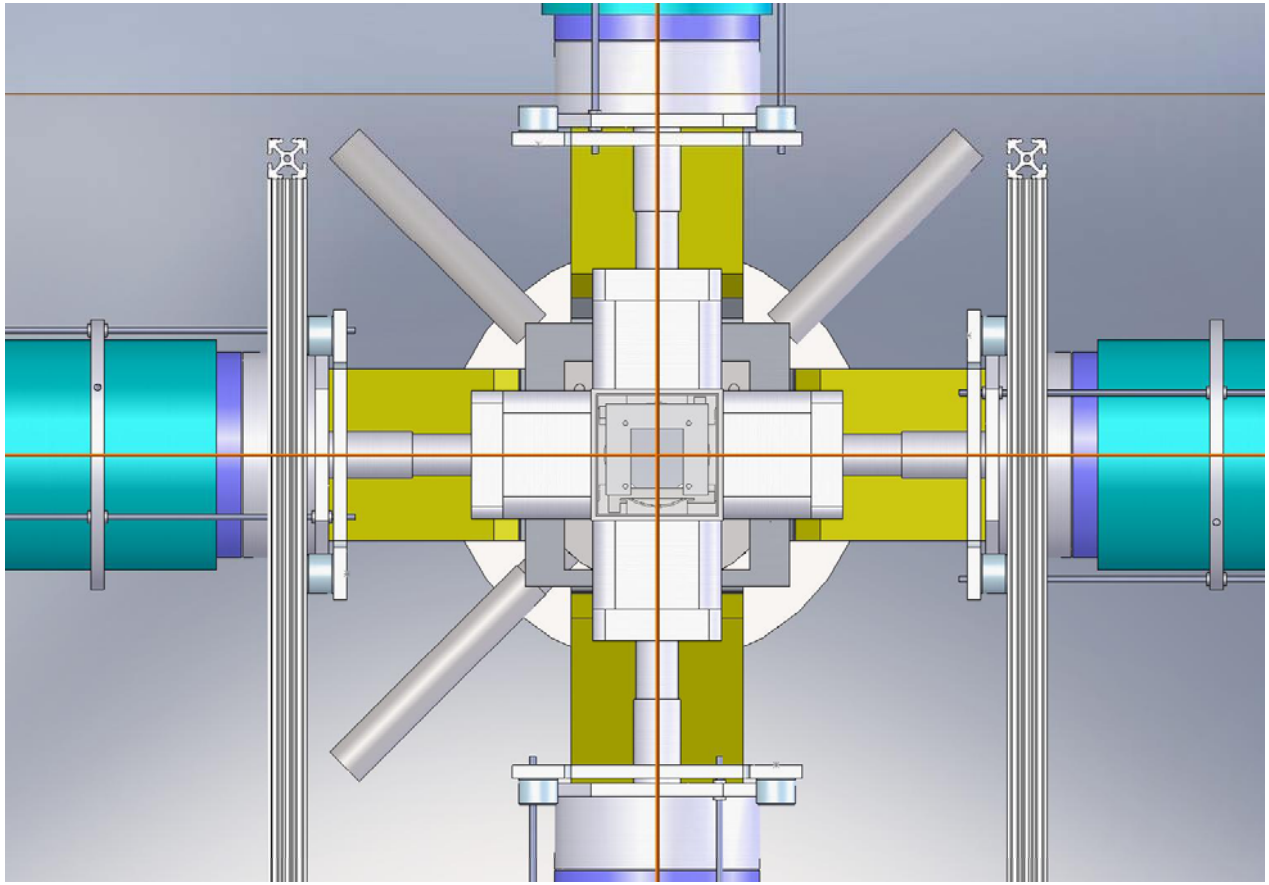
Tape Concept developed from an Ed Zganjar (LSU) design at ISAC…. With modifications for speed and efficiency

TASKS

Test long-running stability in-situ. (new tape)
Determine ultimate maximum speed.
Installed plastic and Si-detectors
Installed germanium counters (TWO)
Install "Scarlet" data acquisition and collect β–γ coincidences in-situ
Investigate shielding.
Multi-scale spectra.

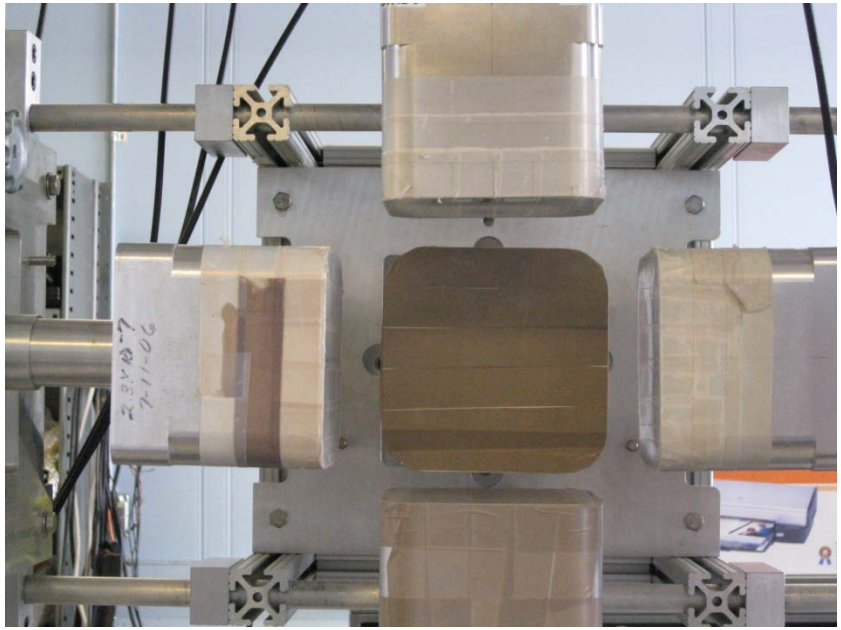
Full test of deflector / tape system
THIS WEEK.

X-array: A decay station for CARIBU and FMA



- 5 clover detectors in a box geometry
- 4, 60mm x 60mm (~200% each) and 1, 70mm x 70mm (300%)
- Funded from L.E. Base Equipment and from this ARRA grant.

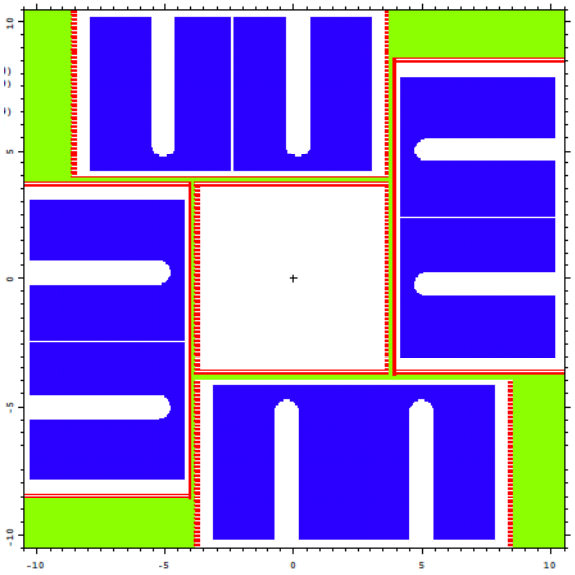
X-Array Status: 08/2011

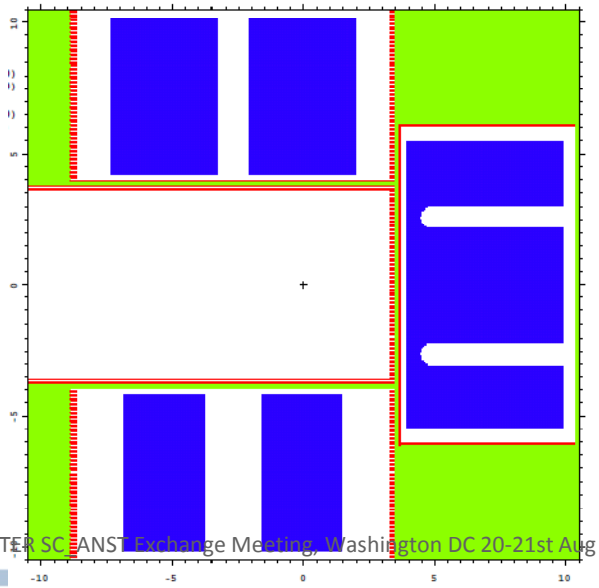


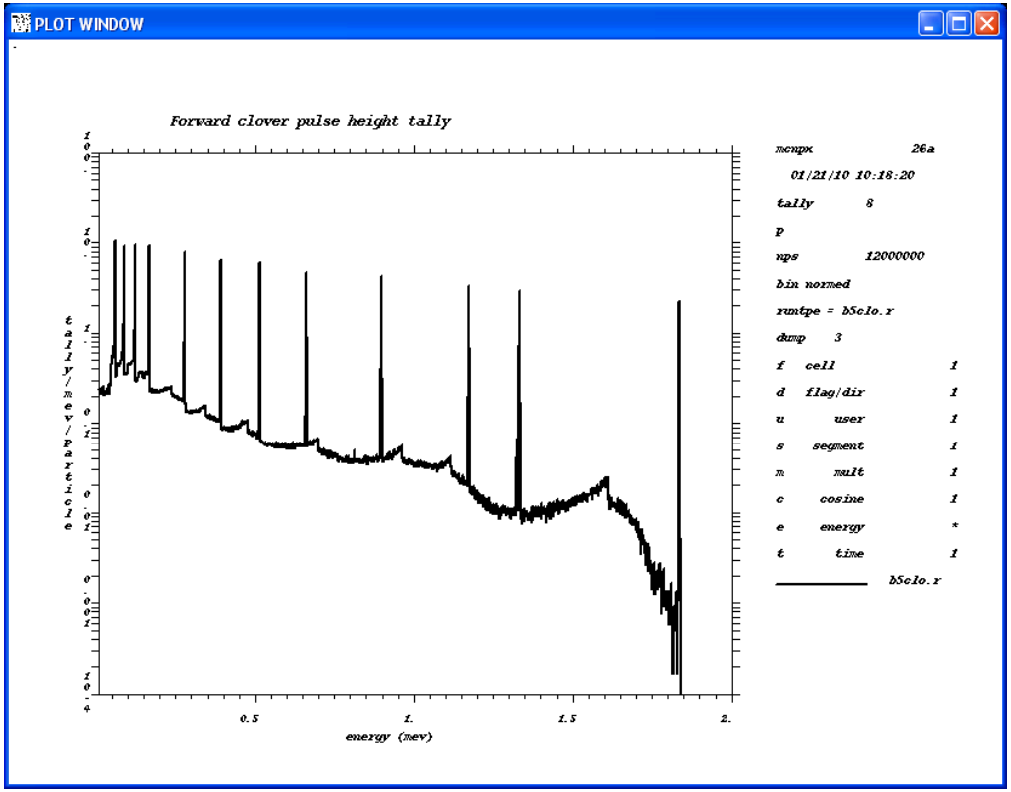
Array complete:-
All detectors working,
Auto-fill for LN_2,
Complete "Scarlet" data acquisition systems.
TASKS
Characterization (Efficiency, Resolution, "add-back" etc)
β-veto plastic paddles (Seweryniak, Rogers)
$LaBr_2$ fast-timing counters (Zhu, Kondev)

2011

Flexible Design to match chambers at CARIBU and FMA





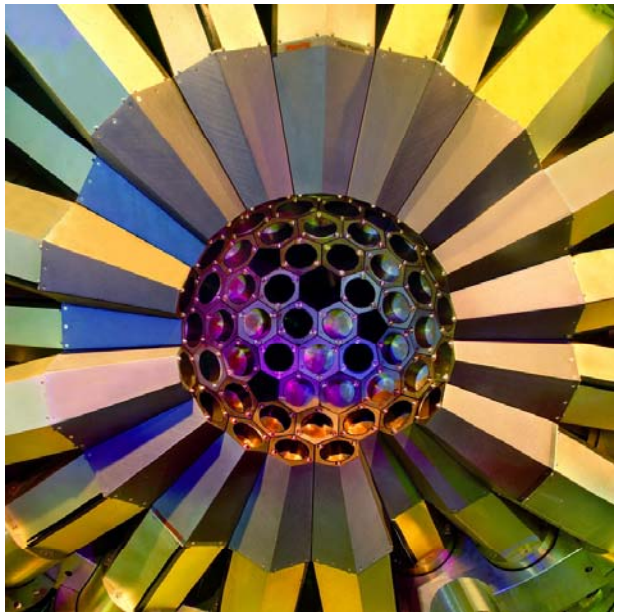


MCNP simulations of performance thanks to E.F. Moore (ANL/RAP)

GEANT 4 simulations of geometry options by M. Smith (ANU)

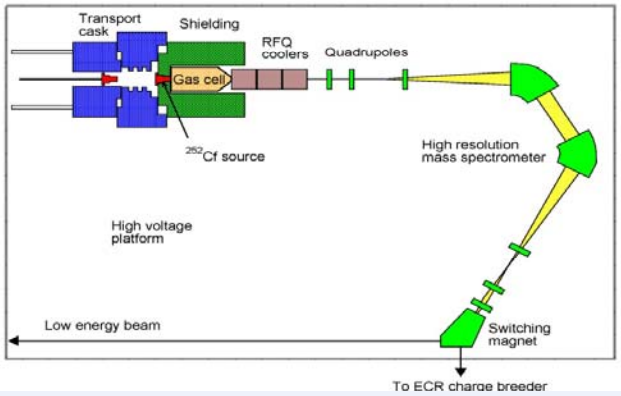
TAGS (Total Absorption Gamma Spectroscopy)

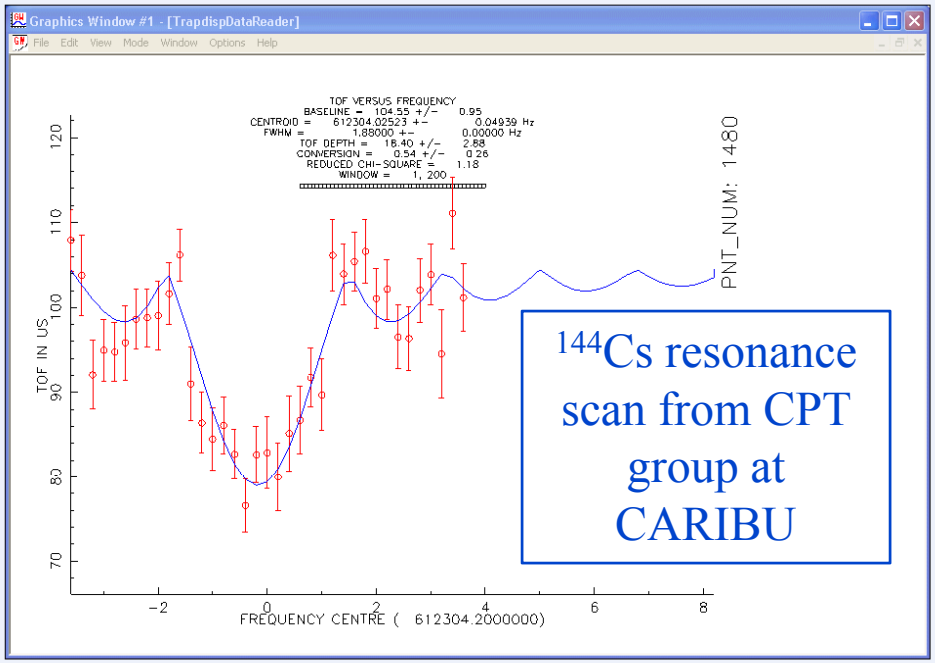
To measure the total gamma flux in decay, including high lying strength, then calorimetry offers an efficient solution.



Several approaches:-
Conventional large NaI(Tl)
Segmented NaI(Tl)
Gammasphere

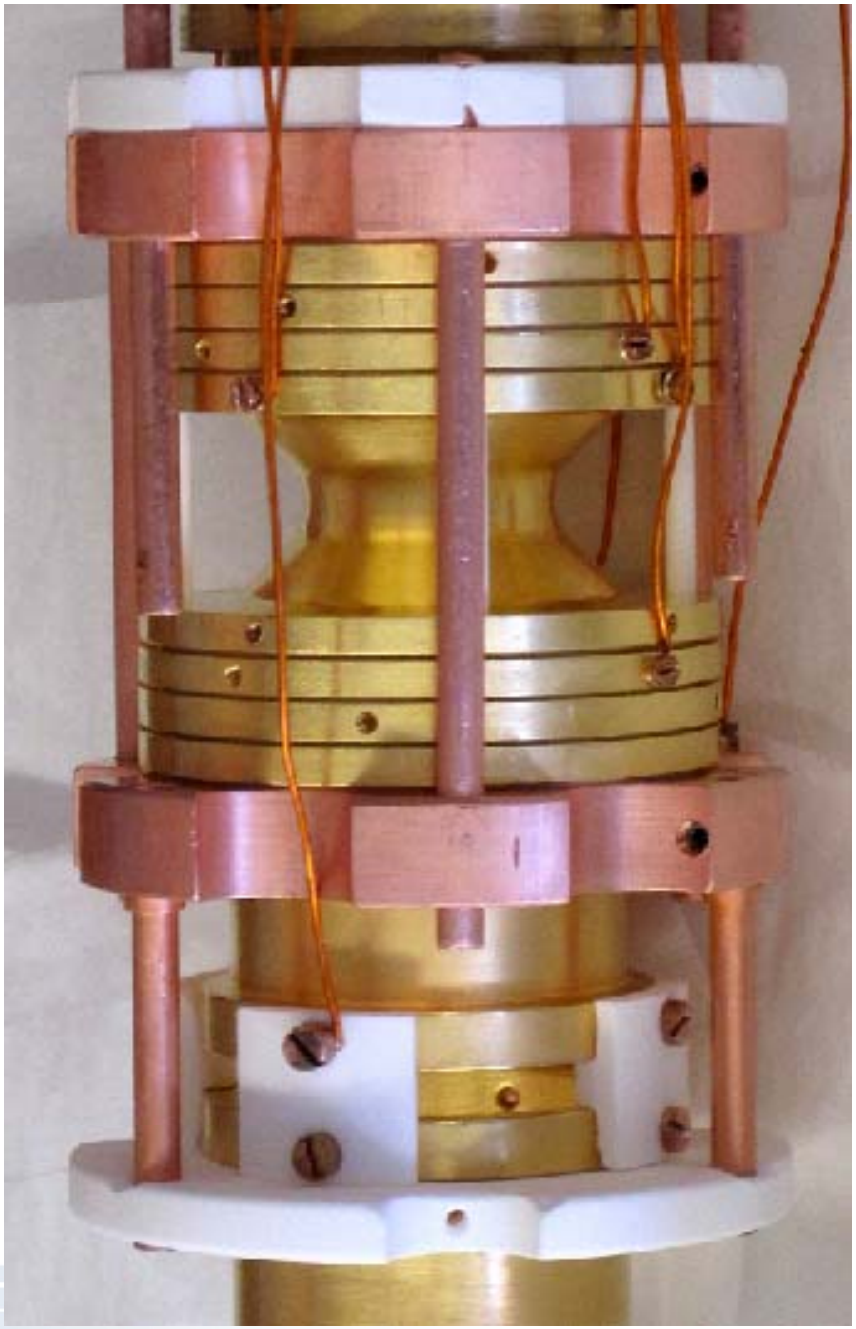
Canadian Penning Trap (CPT) mass spectroscopy





^{144}Cs resonance scan from CPT group at CARIBU

Data from Jon Van Schelt (U of Chicago)



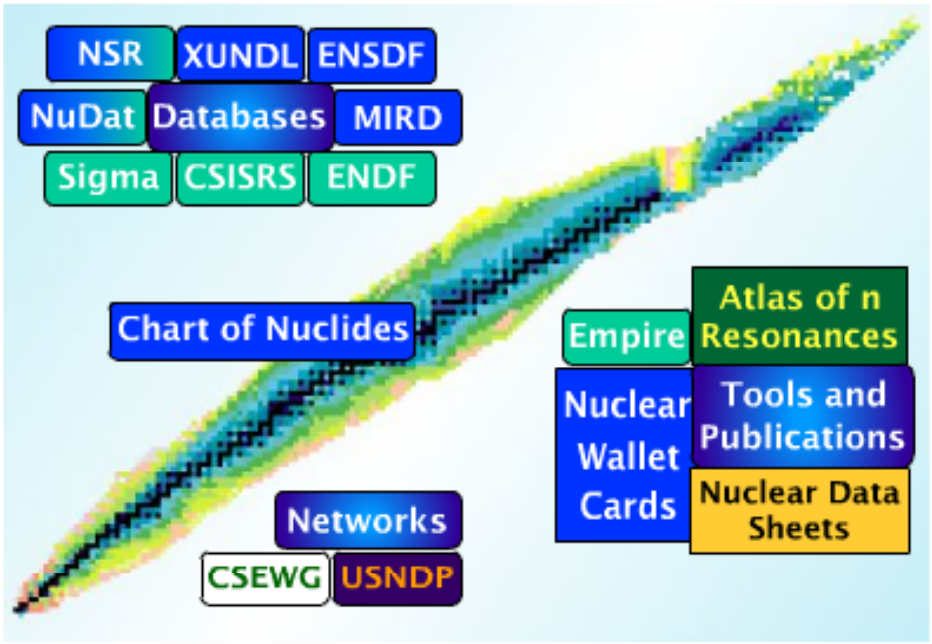
Status

- CARIBU is operating with a ~65 mCi source today. Transitioning from a research project to a day-by-day tool.
- We have isolated (and accelerated) first beams.
- Low Energy Area Infrastructure is installed.
- "Diagnostic" Stub beam line and tape is built.
- "User" beam line is being built (AS WE SPEAK).
- Expect science in FY2011 … i.e. in the next month.

Project Control Milestones

- 5/30/2010: Recruitment of 2.5FTE Post Docs to work on this project.
- 9/30/2010: Construction of Tape Transport System, Installation of X-Array, and Installation of TAGS spectrometer near the CARIBU ion source.
- 9/30/2010: Measurement of the response of the detector system.
- 9/30/2010: Meeting to discuss "Day-1" experiments, based on the international situation (what other groups are making new measurements) and the performance of CARIBU (which isotopes on the IAEA list are being best produced)
- 9/30/2011: Complete initial study of our sensitivity to measure Decay Heat of an isotope on the IAEA list and establish precision of strength-function.
- 9/30/2012: Publish first results of decay heat of refractory elements for which we should have unique capability.

Acknowledgement



NNDC National Nuclear Data Center

BROOKHAVEN NATIONAL LABORATORY

Nuclear Structure and Decay Databases

Nuclear Structure and Decay Tools

Nuclear Reaction Databases

Nuclear Reaction Tools

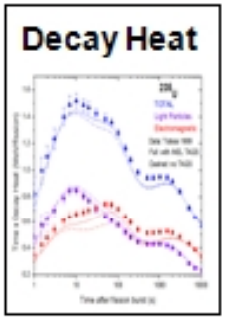
Bibliography Databases

Networks and Links

About the Center

Publications

Meetings



NEW Summer Nuclear Data Week, Montauk, NY, June 20-24

Good Data Bases are essential for this fast-moving field