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Nuclear Structure and Decay Properties and Their Relevance to R&D Needs for AFC

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Office of Science
U.S. DEPARTMENT OF ENERGY

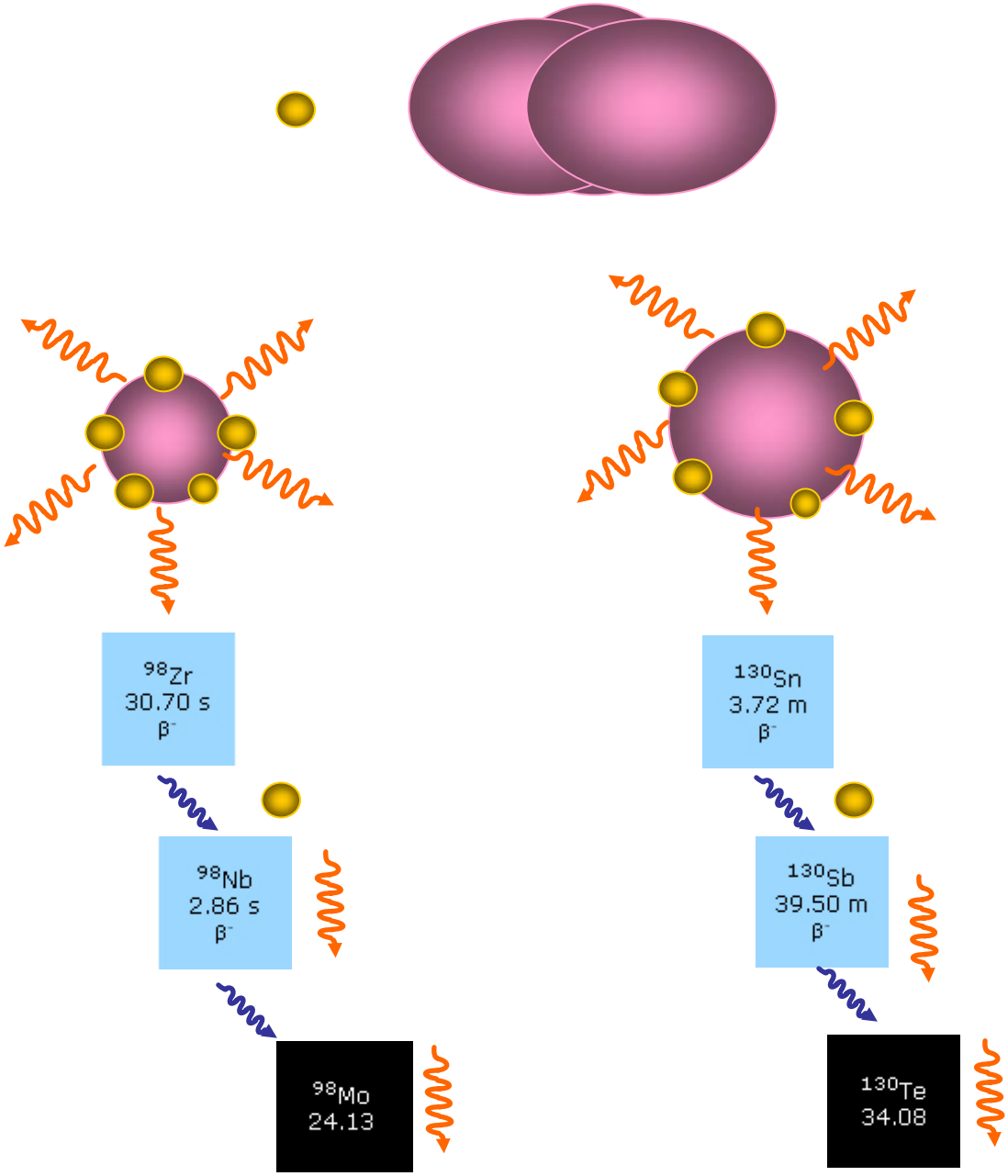
A U.S. Department of Energy laboratory managed by The University of Chicago

Workshop on Nuclear Physics and Related Computational Science R&D for Advanced Fuel Cycles

Bethesda, Maryland, August 10-12, 2006

Relevance of Structure and Decay Data to AFC applications

- Accurate nuclear structure and decay data are important to many reactor physics applications
  - ✓ Decay heat – fission products (short cooling times, e.g. <1 year) & actinides (long cooling times, e.g. > 1 year)
  - ✓ Cross section measurements and their interpretation – activation and prompt (n,xnγ) techniques
  - ✓ Provide important input to reaction model calculations – level densities, radiation strength functions, spin populations, etc.
  - ✓ Material accountability and safeguards, radiation shielding and more
- Will give selected examples and outline some areas (from my perspective) where future research at the national Nuclear Physics facilities can contribute to the R&D needs for AFC



~200 MeV/fission

TKE of fission fragments

~165 MeV – ~ 82%

prompt neutrons and γ's

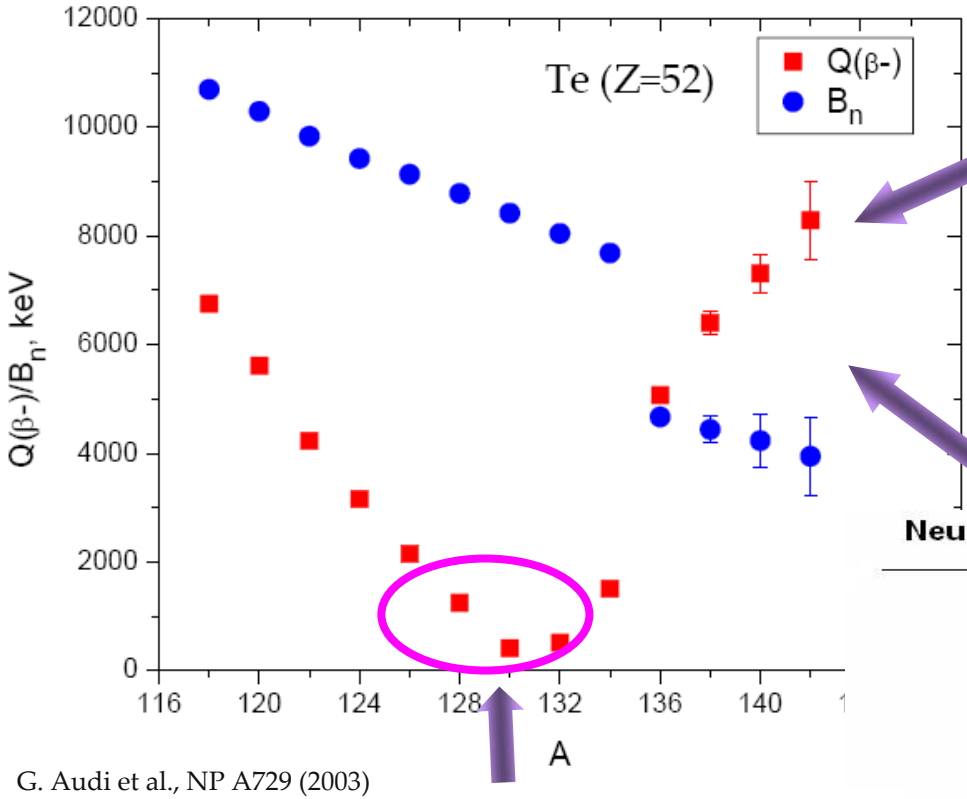
~12 MeV - ~6%

β– particles, γ 's, ICC & delayed neutrons

~15 MeV - ~8%

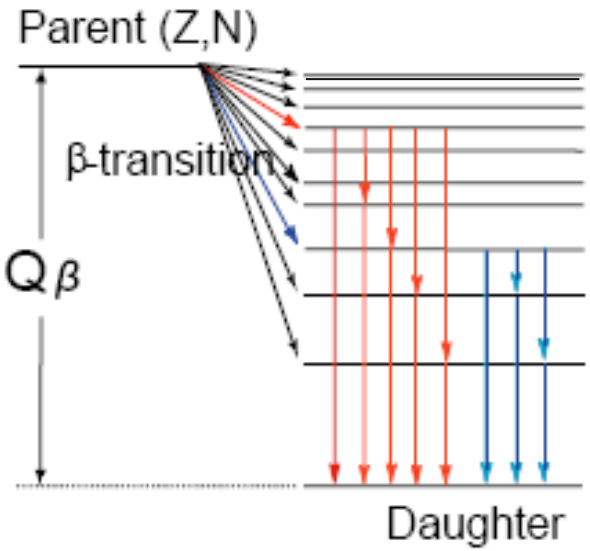
~1200 nuclei

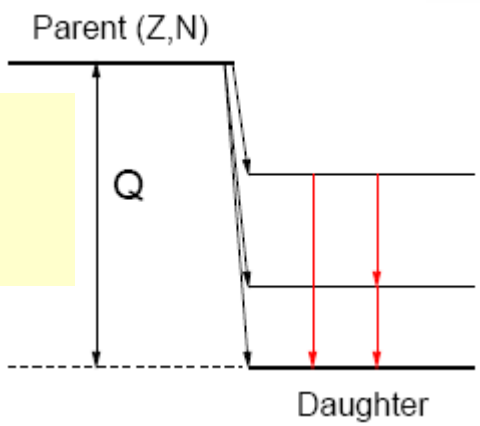
β– decay of N-rich nuclei

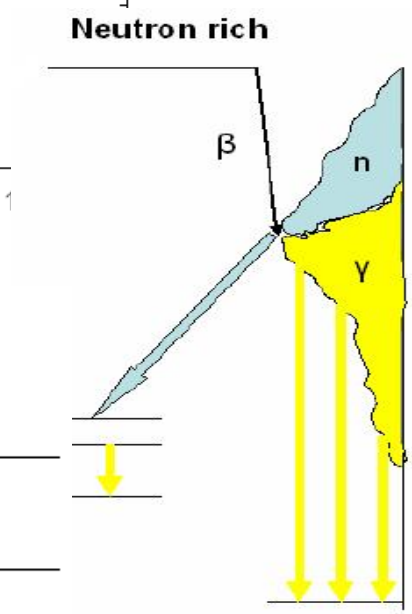


G. Audi et al., NP A729 (2003)

"large" $Q_{\beta-}$ – large density of levels and more complicated decay schemes – usually low γ–ray multiplicities, but isomers!







"small" $Q_{\beta-}$ - the level schemes are well understood

$Q_{\beta-} > B_n$

What we want to know accurately?

Key observable

β– feeding intensity

$$S_\beta(E) = \frac{I_\beta(E)}{f_n(Q_\beta - E, Z)T_{1/2}} = \frac{1}{f_n t}$$

statistical rate function (phase-space factor)

Level half-life

Nuclear Structure

$$S_\beta(E) \propto \left|M_{fi}\right|^2$$

Decay Heat

Beta's

$$H_\beta(t) = \lambda N(t)\overline{E_\beta}$$

$$\overline{E_\beta} = \sum_i E_\beta^i I_\beta^i + \sum_k E_{\beta A}^k I_{\beta A}^k + \sum_m E_{CE}^m I_{CE}^m$$

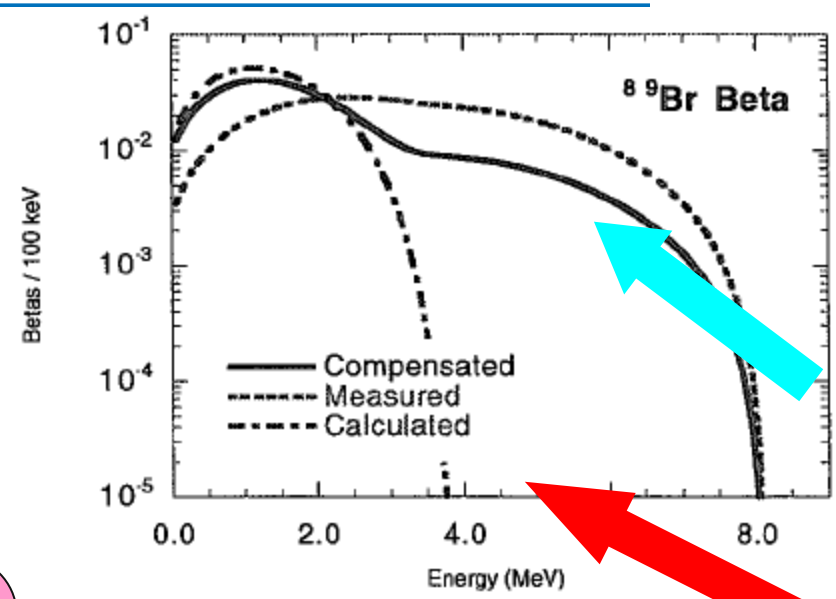
Gamma's

$$H_\gamma(t) = \lambda N(t)\overline{E_\gamma}$$

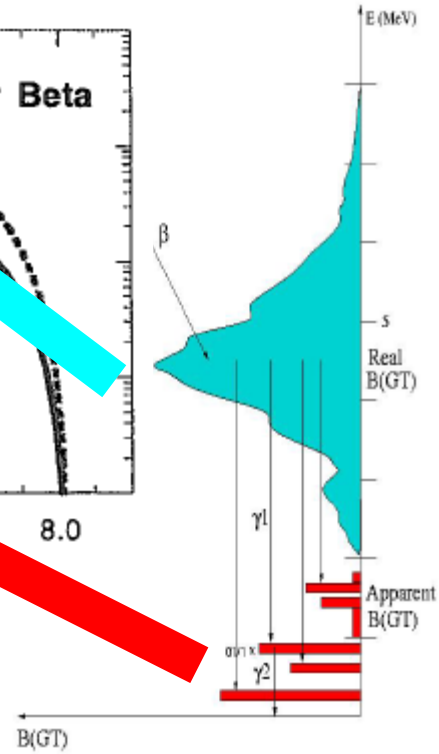
$$\overline{E_\gamma} = \sum_i E_\gamma^i I_\gamma^i + \sum_k E_X^k I_X^k + \sum_m \overline{E_{\beta,BS}^m} I_\beta^m + \sum_l 1.022 I_\beta^l$$

Current status of decay data libraries

- to a large extend incomplete especially for neutron-rich FP

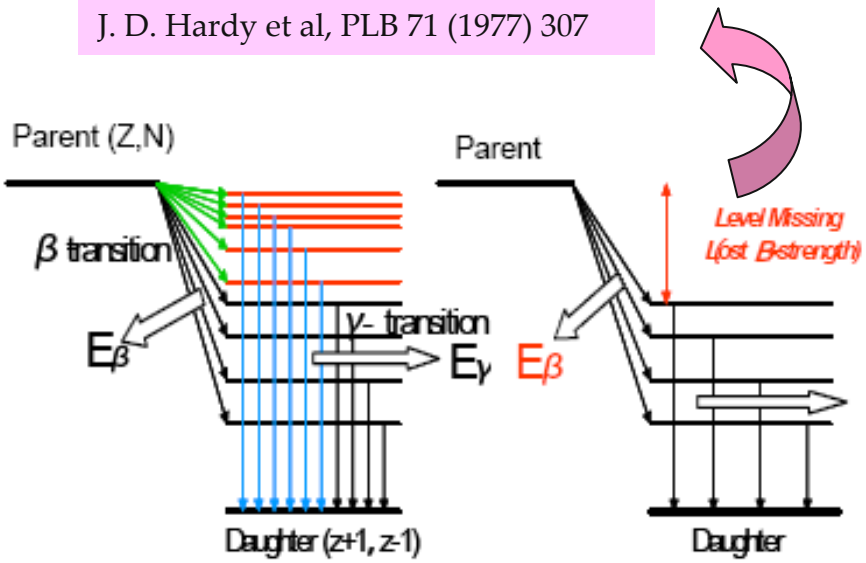


J. Katakura et al, JNST, 2002,444



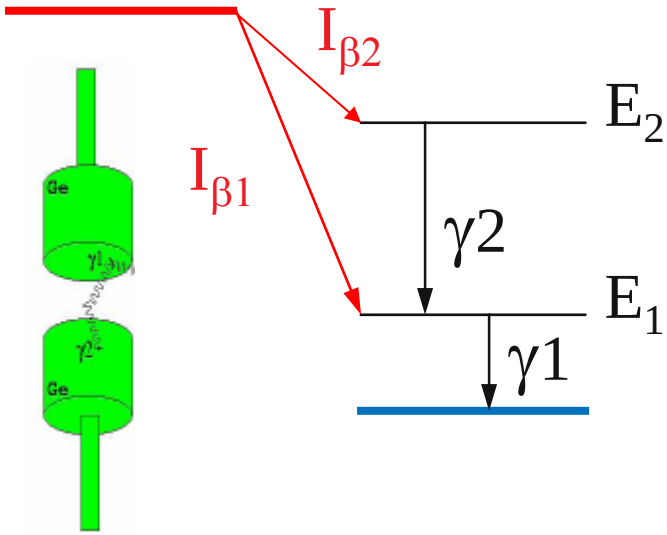
"Pandemonium" effect

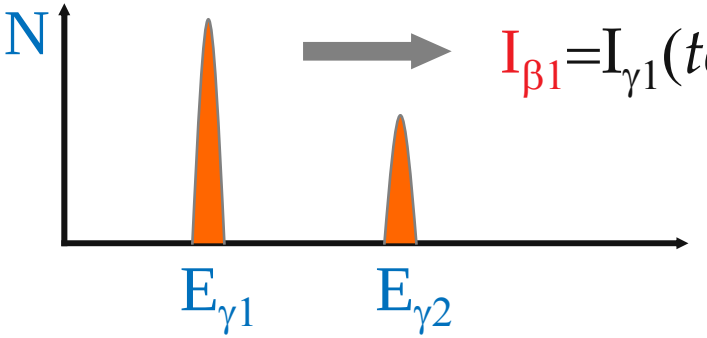
J. D. Hardy et al, PLB 71 (1977) 307



- JENDL FP (based on ENSDF) - "contaminated" by gross beta-decay theory for ~500 FP (almost half of all FP)!
- there are significant differences between various libraries, e.g JEFF vs. JENDL

High-resolution Gamma-ray spectroscopy (HRGS)

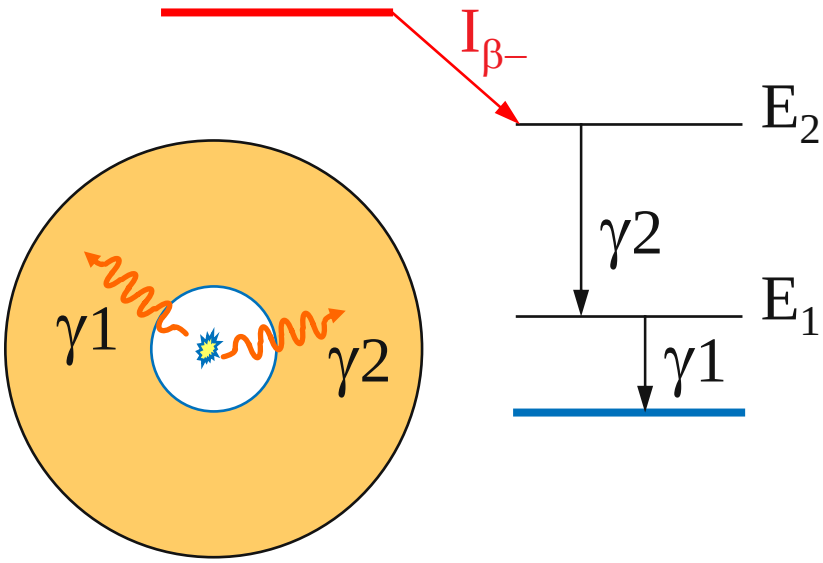


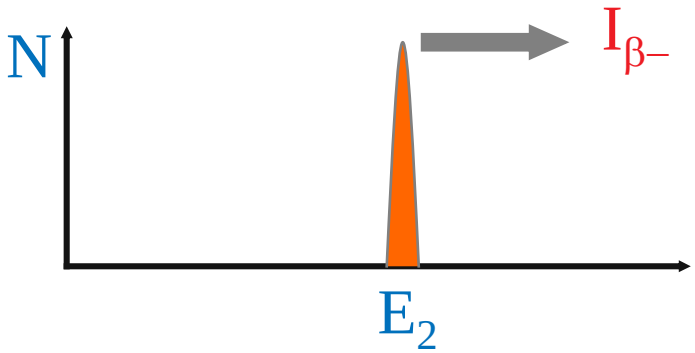


$$I_{\beta 1} = I_{\gamma 1}(tot) - I_{\gamma 2}(tot)$$

- depends on the accurate knowledge of the decay scheme – level energies, J^{π}, mult., ICC
- not studied with state-of-the art equipments – low sensitivity & effect of the "Pandemonium"

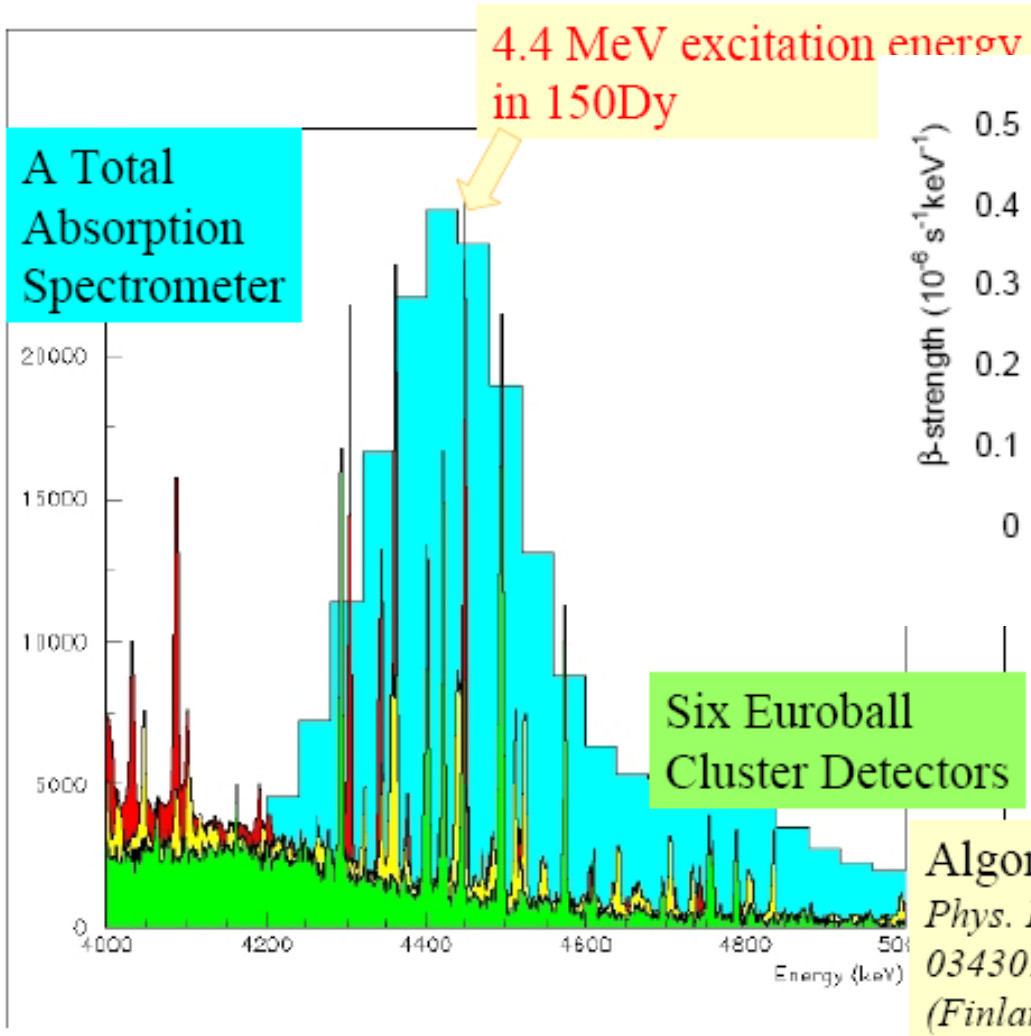
Total Absorption Gamma-ray Spectroscopy (TAGS)



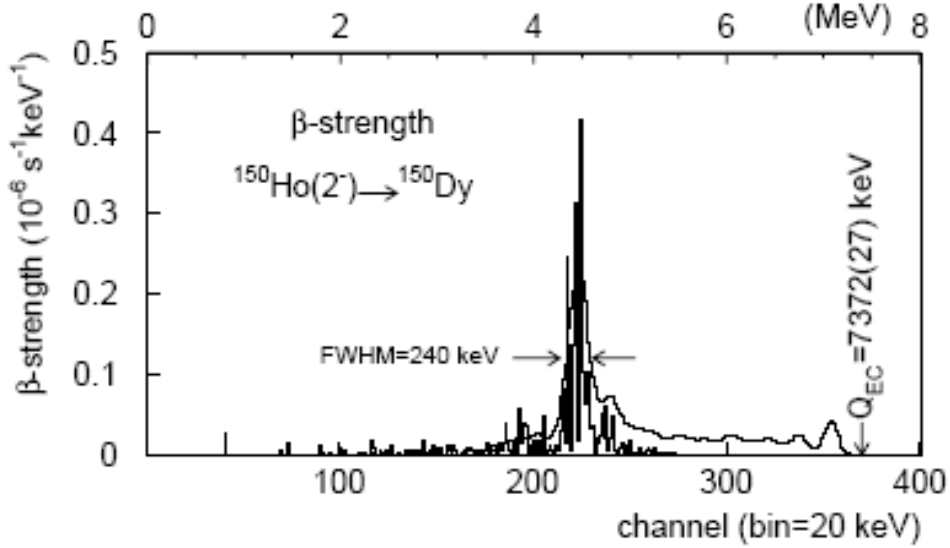


- Compromised when isomeric states are presented
- Compromised when β^-n are emitted
- Compromised by isotope/isobar contaminations

We need both - HRGS and TAGS!



Q(EC) = 7.4 MeV



Algora et al
Phys. Rev C 68 (2003) 034301 and ENAM 20 (Finland)

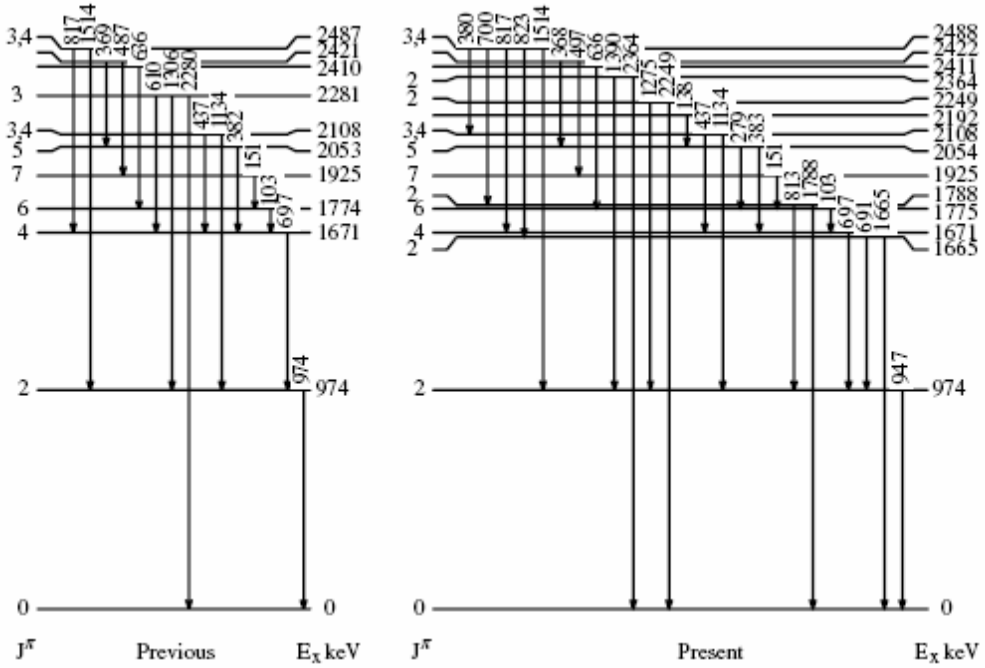
Opportunities at the existing RB facilities

PHYSICAL REVIEW C **71**, 044311 (2005)

γ-ray spectroscopy of ^{132}Te through β decay of a ^{132}Sb radioactive beam

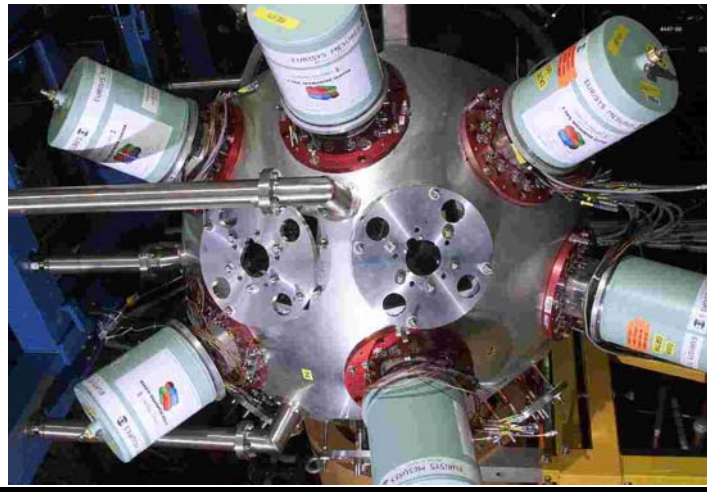
R. O. Hughes,[1,2] N. V. Zamfir,[1,3,4] D. C. Radford,[5] C. J. Gross,[5] C. J. Barton,[6] C. Baktash,[5] M. A. Caprio,[1,7] R. F. Casten,[1] A. Galindo-Uribarri,[5] P. A. Hausladen,[5] E. A. McCutchan,[1] J. J. Ressler,[1] D. Shapira,[5] D. W. Stracener,[5] and C.-H. Yu[5]

- ✓ using ^{132}Sb beam (10^7 pps) at 396 MeV produced from proton-induced fission



- ✓ Significantly revised level scheme
- ✓ More than 195 new transitions added

CLARION – 11 Clovers, ORNL

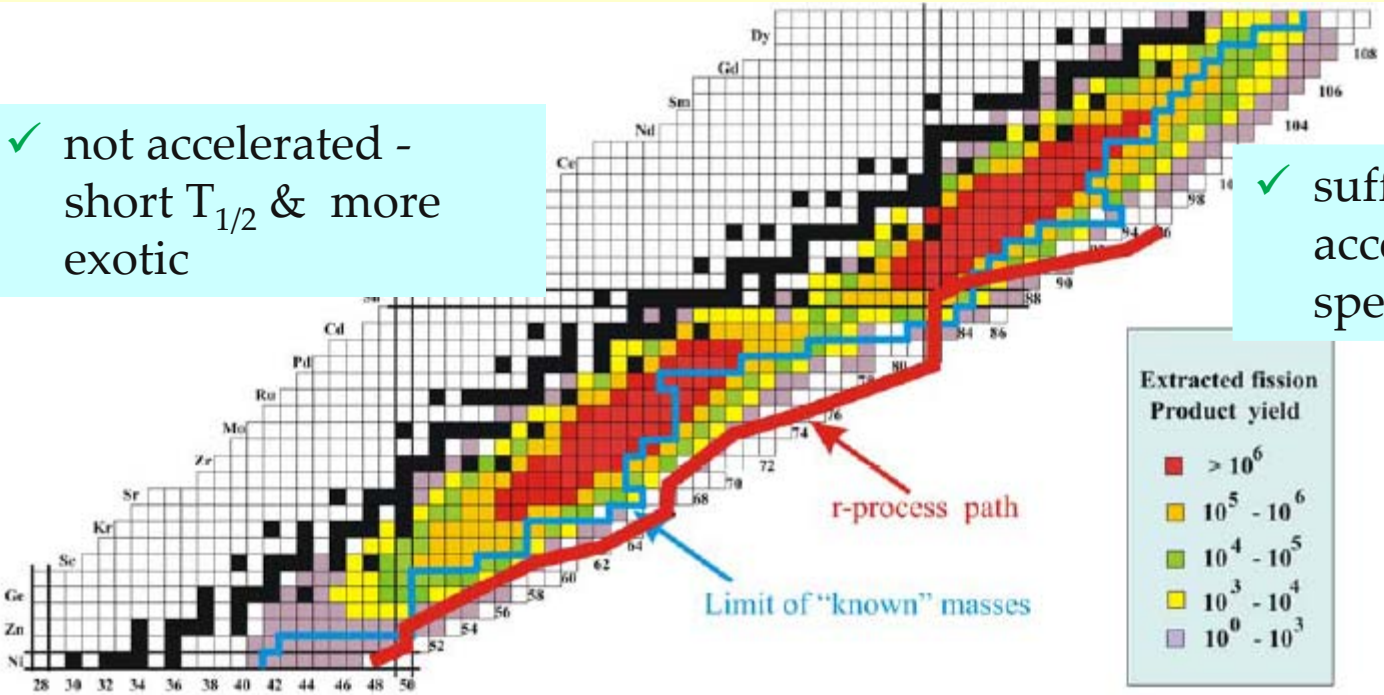


Opportunities with CARIBU at ATLAS

- using a ^{252}Cf SF source, gas catcher & ECR technology with post-acceleration by ATLAS

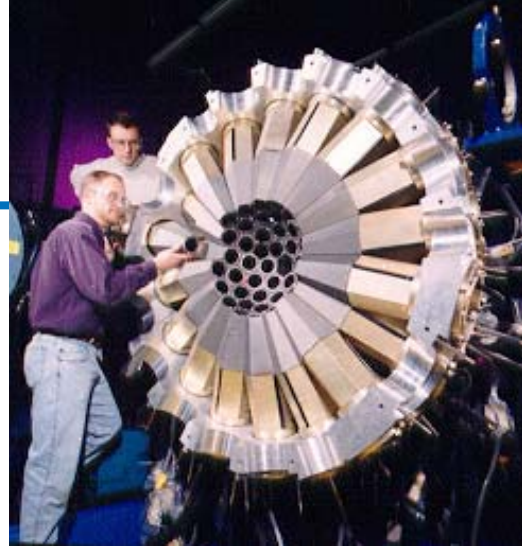
✓ not accelerated - short $T_{1/2}$ & more exotic

✓ sufficient yields for post-accelerated FP decay spectroscopy



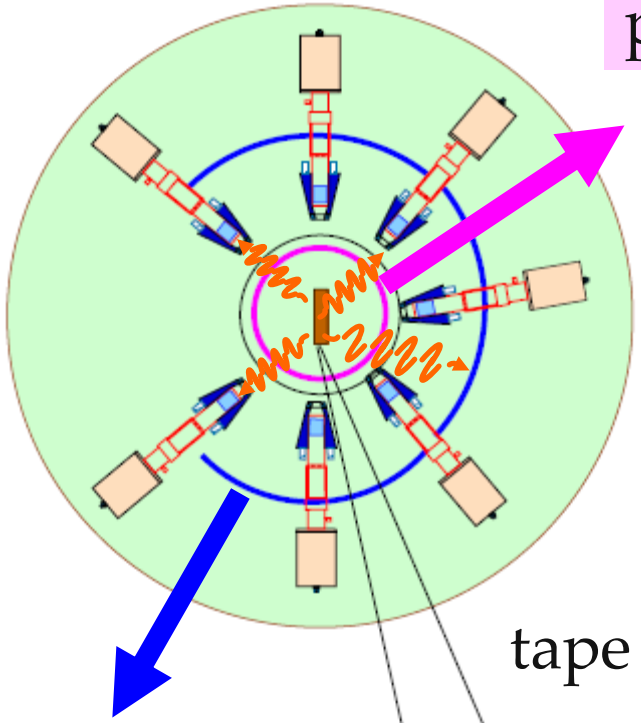
unique opportunities to improve the needed decay data by using both the discrete HRGS and TAGS

β– counting station with GS



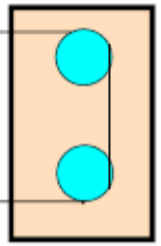
GAMMASPHERE

plastic scint. (β–)

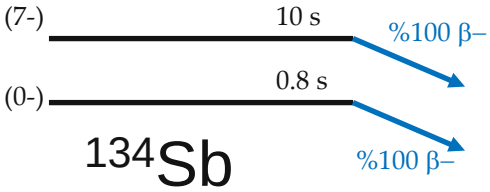


heavy scintillator filling holes

tape system



- ✓ high resolution & sensitivity
- ✓ powerful β–γ–γ coin – resolving week cascades & isomers!

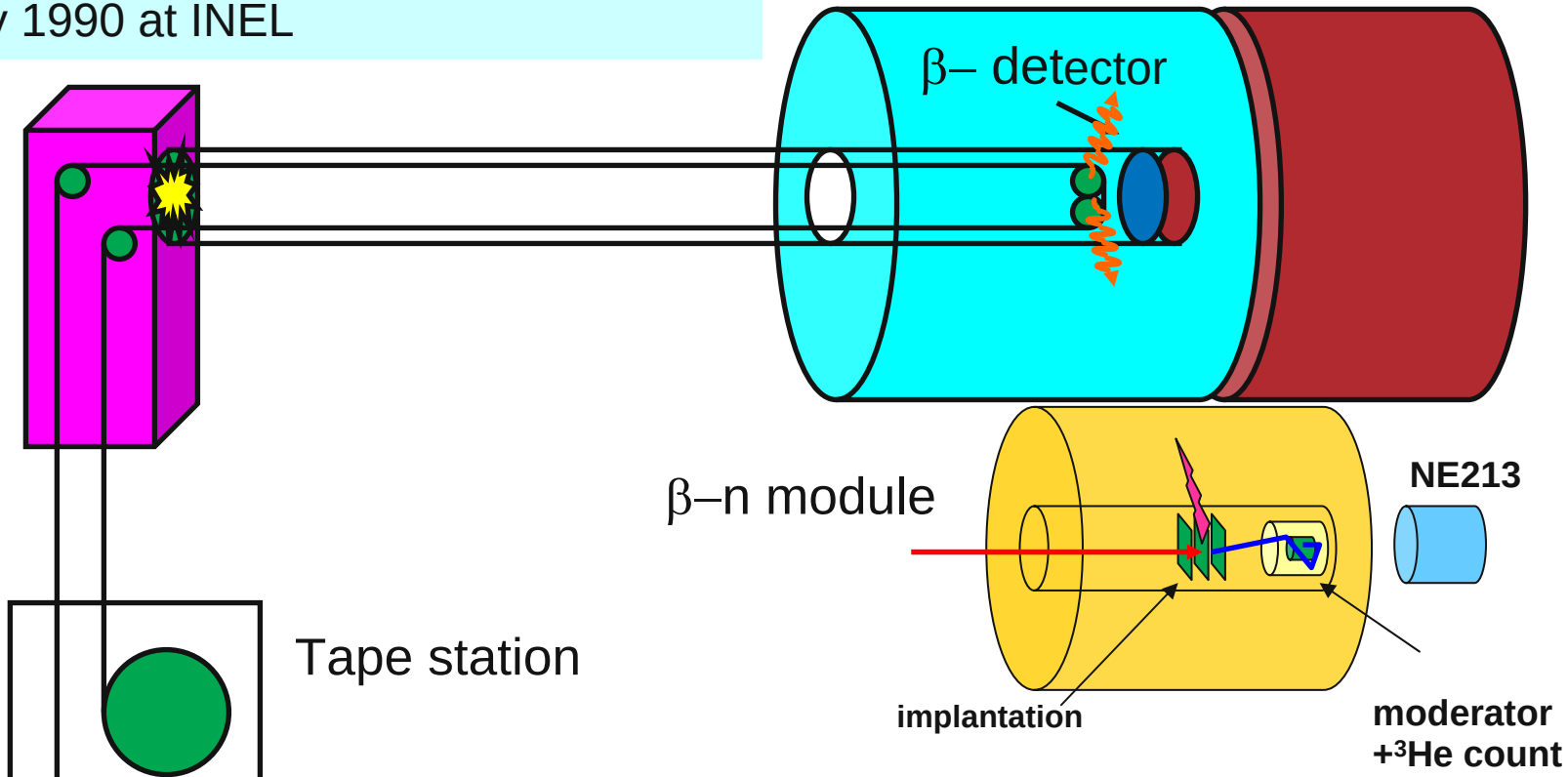


GS as a calorimeter

- ✓ P. Reiter et al. Phys.Rev.Lett. 84, 3542 (2000)
- ✓ with a modest upgrade – suitable for β– decay studies – HRGS & TAGS

Dedicated TAGS spectrometer

successfully operated by R.C. Greenwood et al. in early 1990 at INEL



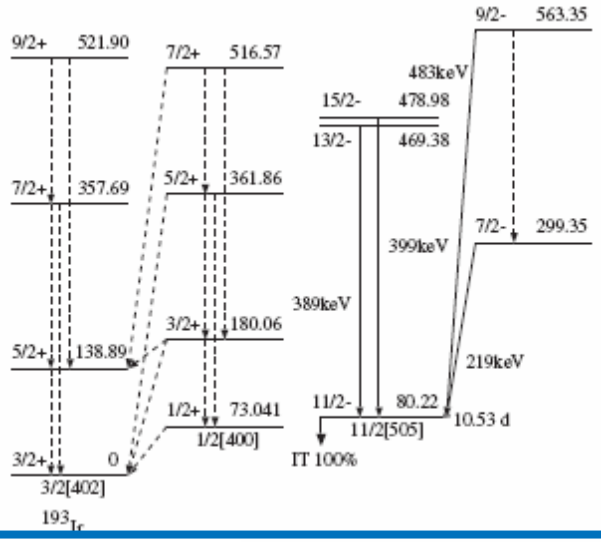
- ✓ well-type spectrometer close to 4π geometry
- ✓ will require a special design – NaI/Ge – granularity?
- ✓ best available energy resolution to allow fine structure in β– strength distribution to be observed

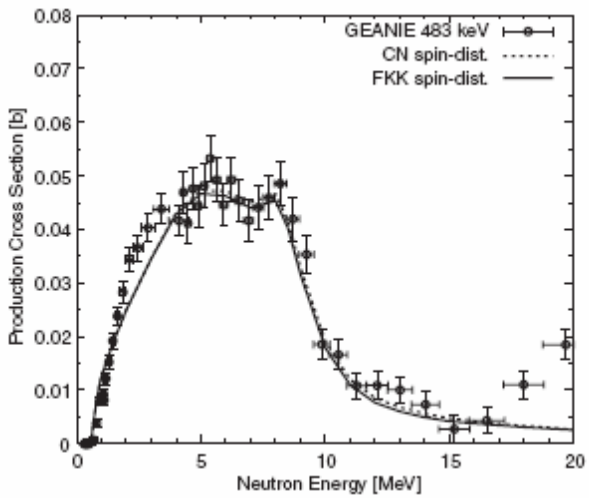
Production of isomers by neutron-induced inelastic scattering on ^{193}Ir and influence of spin distribution in the pre-equilibrium process

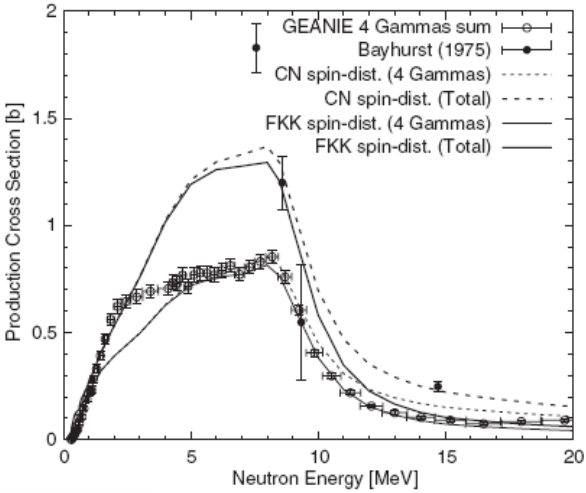
Toshihiko Kawano*, Patrick Talou, Mark B. Chadwick

Los Alamos National Laboratory, NM 87545, USA

reactions model development







States in ^{197}Au from the $(n, n'\gamma)$ reaction

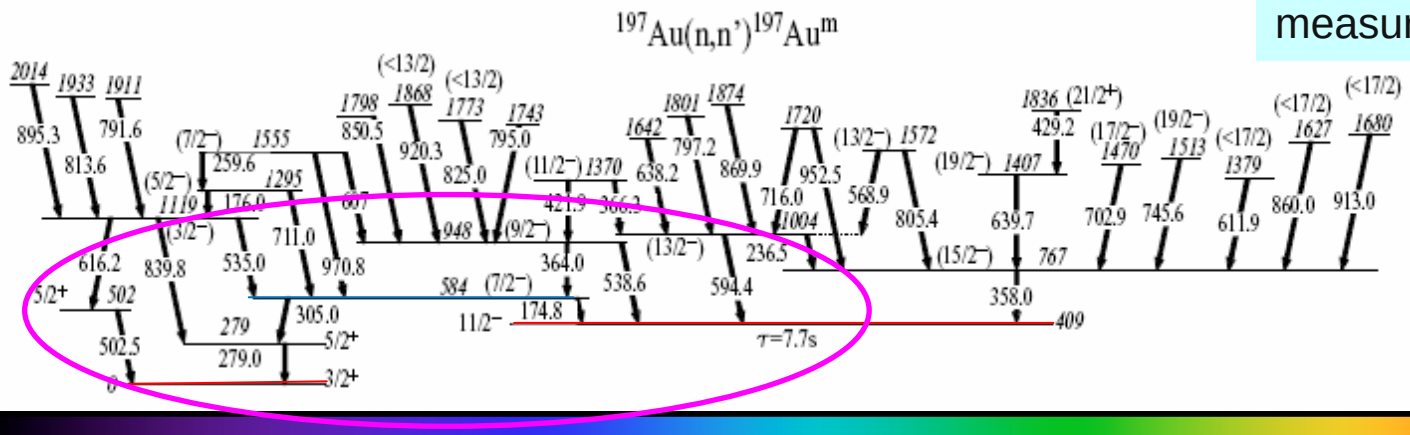
N. Fotiades,[1] R. O. Nelson,[1] M. Devlin,[1] K. Starosta,[2] J. A. Becker,[3] L. A. Bernstein,[3] P. E. Garrett,[3,*] and W. Younes[3]

[1]*Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*

[2]*NSCL/Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA*

[3]*Lawrence Livermore National Laboratory, Livermore, California 94550, USA*

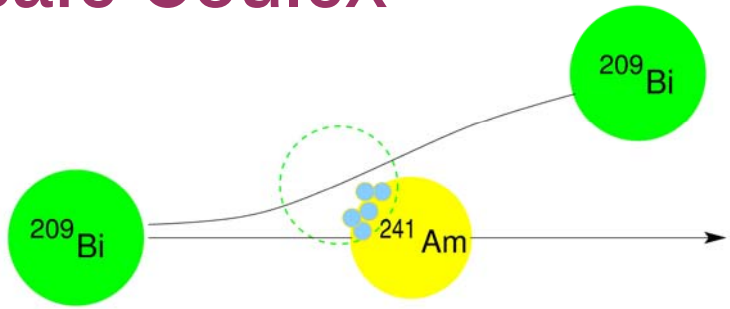
interpreting the results from CS measurements

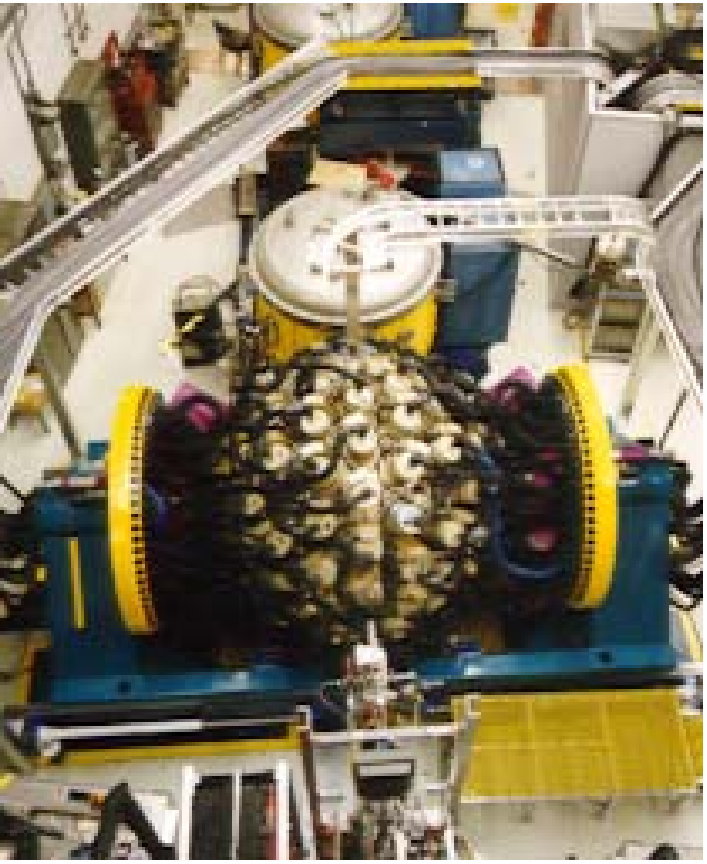


``Unsafe Coulex''

- Thick targets! Bigger Yield!
- ~15% above the Coulomb barrier

Beams: ^{207}Pb, ^{208}Pb, ^{209}Bi ~1.4 GeV





^{246}Cm – $T_{1/2}$=4.7x10^{3} yr

^{248}Cm – $T_{1/2}$=3.4x10^{5} yr

^{241}Am – $T_{1/2}$=4.3x10^{2} yr

^{239}Pu – $T_{1/2}$=2.4x10^{4} yr

^{240}Pu – $T_{1/2}$=6.6x10^{3} yr

^{242}Pu – $T_{1/2}$=3.8x10^{5} yr

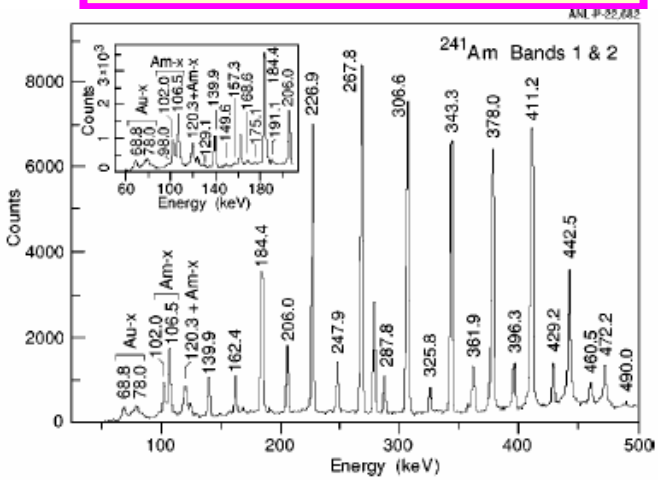
^{244}Pu – $T_{1/2}$=8.3x10^{7} yr

^{237}Np – $T_{1/2}$=2.1x10^{6} yr

^{232}Th – $T_{1/2}$=1.4x10^{10} yr

Many transfer channels are open!

Access to neighboring nuclei!



K. Abu-Saleem, PRC70 (2004) 024310

To summarize …

- Accurate Nuclear Structure & Decay Data are important to many AFC applications
- The existing and future RB facilities such as HRIBF at ORNL & CARIBU at ATLAS, ANL offer excited opportunities to improve significantly the FP decay data that are needed for reactor physics applications (decay heat)
  - ✓ Capability to combine the HR γ–ray spectroscopy with TAGS would be an asset and worth developing
- Continuing studies of MA using "Unsafe Coulex" is desirable
- Actinide decay data – an ongoing IAEA CRP on "Updated decay data library for actinides" – recommendations for new decay measurements – emission probabilities, BR & $T_{1/2}$ – series of measurements were initiated at ANL and other labs