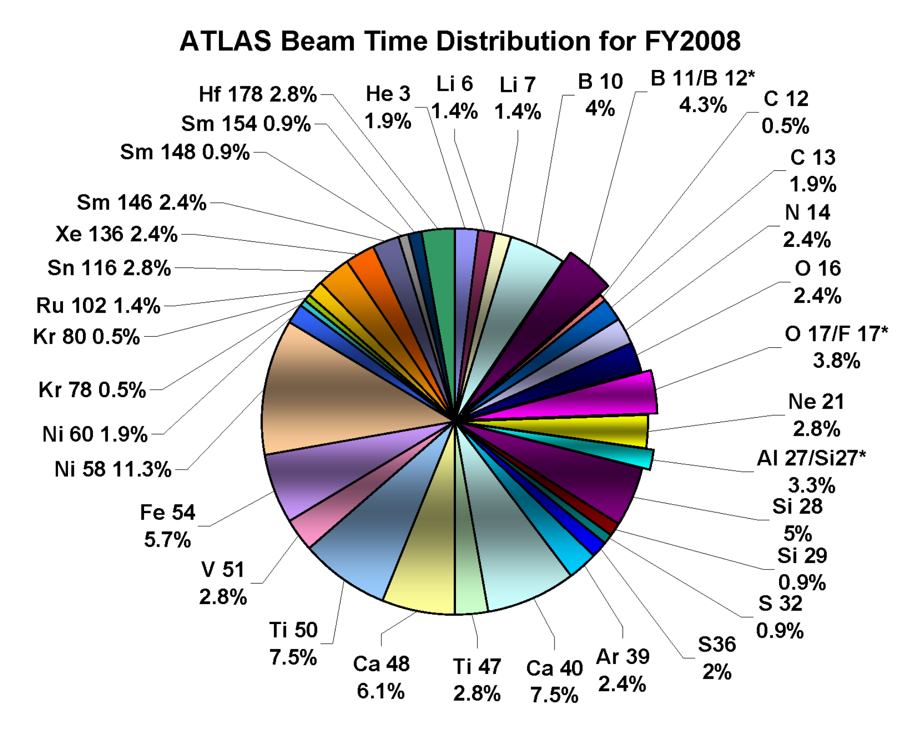
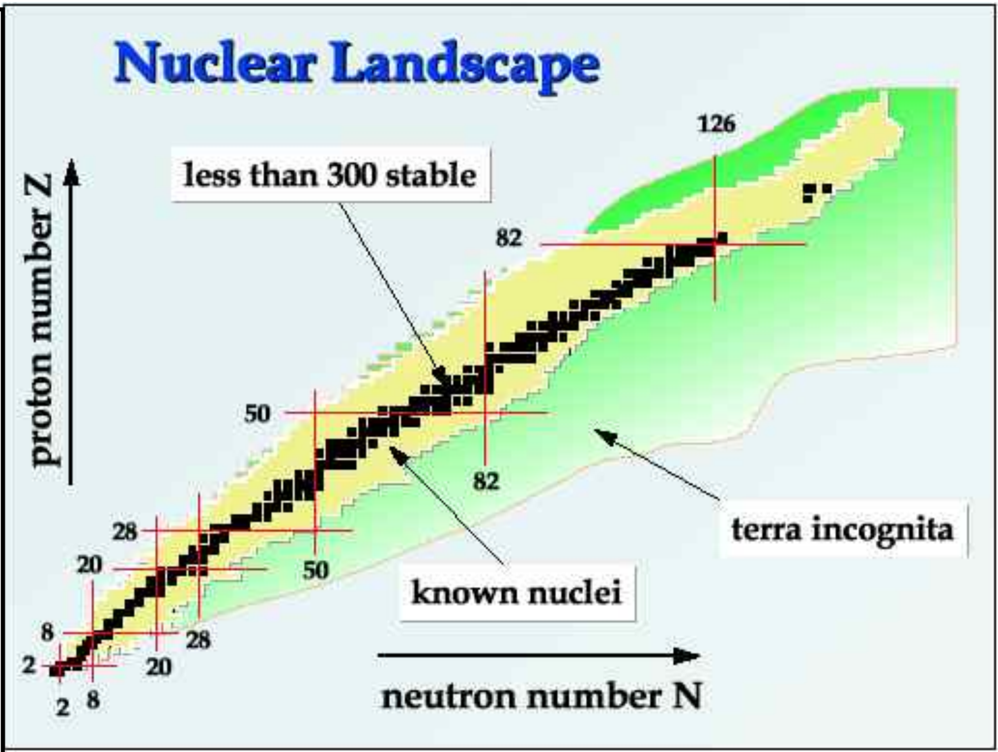
Nuclear Data research capabilities at ANL of relevance to the IAEA CRP on "Nuclear Data for Charged-particle Monitor Reactions and Medical Isotopes Production"

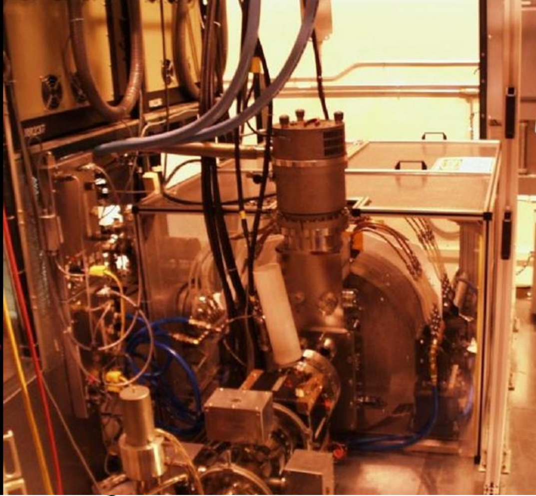
kondev@anl.gov

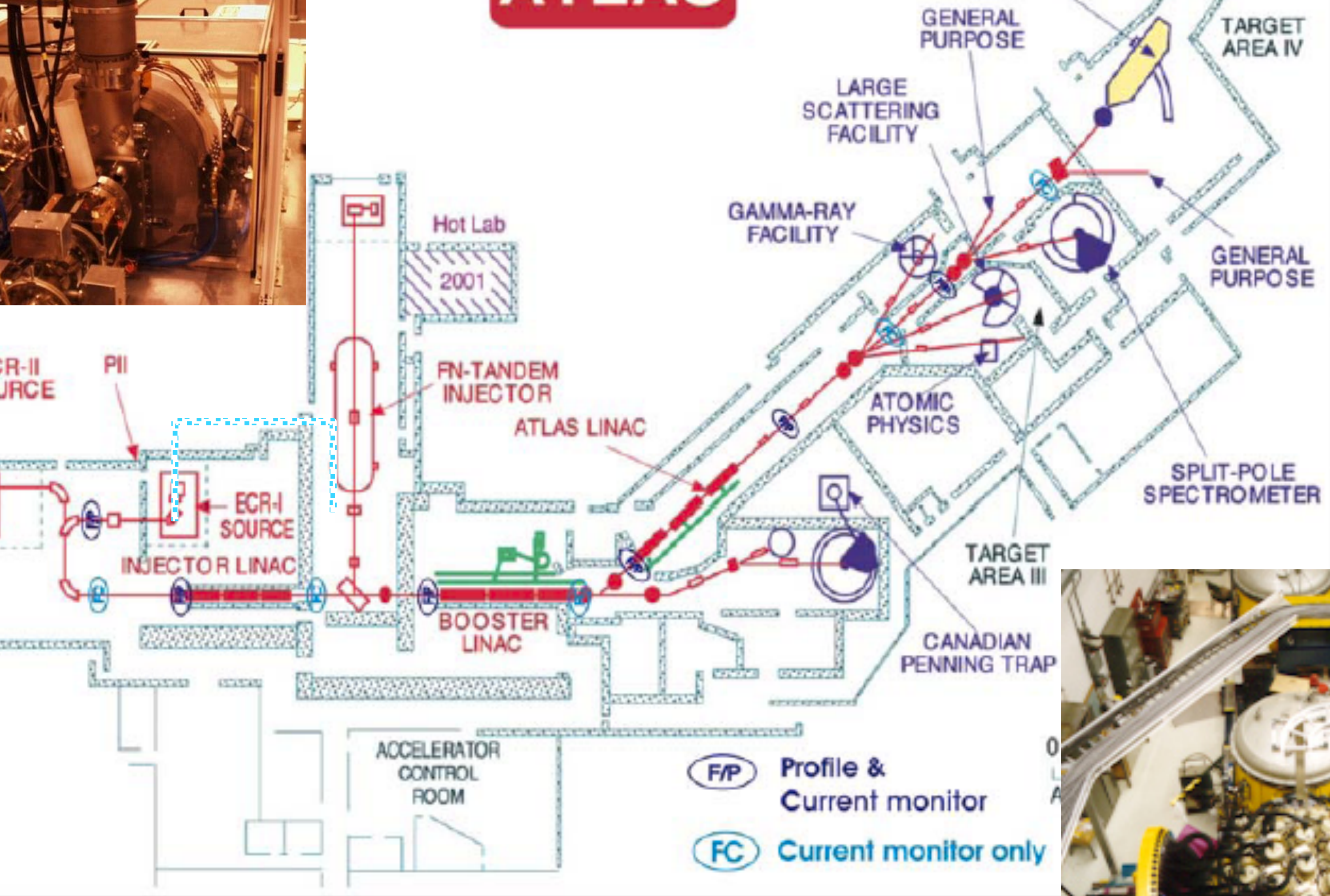
Argonne Tandem Linac Accelerator System

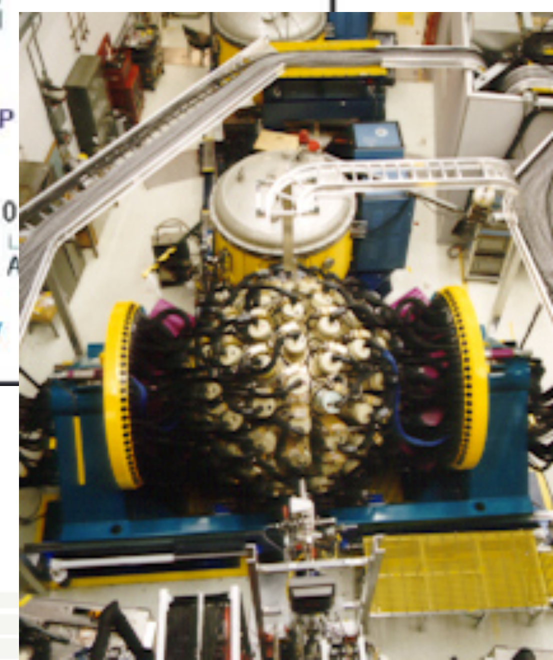
- Office of Science, US DOE (Office of Nuclear Physics) **user** facility
  - ✓ proposals submitted to Program Advisory Committee (PAC)
  - ✓ no cost to researchers for approved proposals
- Stable beam facility (the only stable beam user facility in US!)
  - ✓ accelerate all stable nuclei – from p to ^{238}U (and some rare beams)
  - ✓ energy region – near and above the Coulomb barrier – 6-8 MeV/u
  - ✓ exceptional beam quality: spot size, time & energy resolutions, flexibility



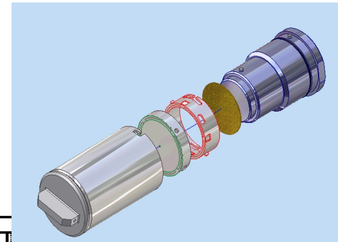


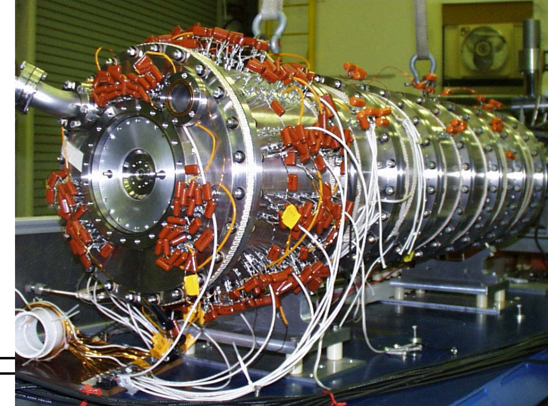



ATLAS
FRAGMENT MASS ANALYZER
GENERAL PURPOSE
TARGET AREA IV
LARGE SCATTERING FACILITY
GAMMA-RAY FACILITY
Hot Lab
2001
GENERAL PURPOSE
FN-TANDEM INJECTOR
ATLAS LINAC
ATOMIC PHYSICS
SPLIT-POLE SPECTROMETER
ECR-II SOURCE
PII
ECR-I SOURCE
INJECTOR LINAC
BOOSTER LINAC
TARGET AREA III
CANADIAN PENNING TRAP
ACCELERATOR CONTROL ROOM
F/P
Profile & Current monitor
FC
Current monitor only



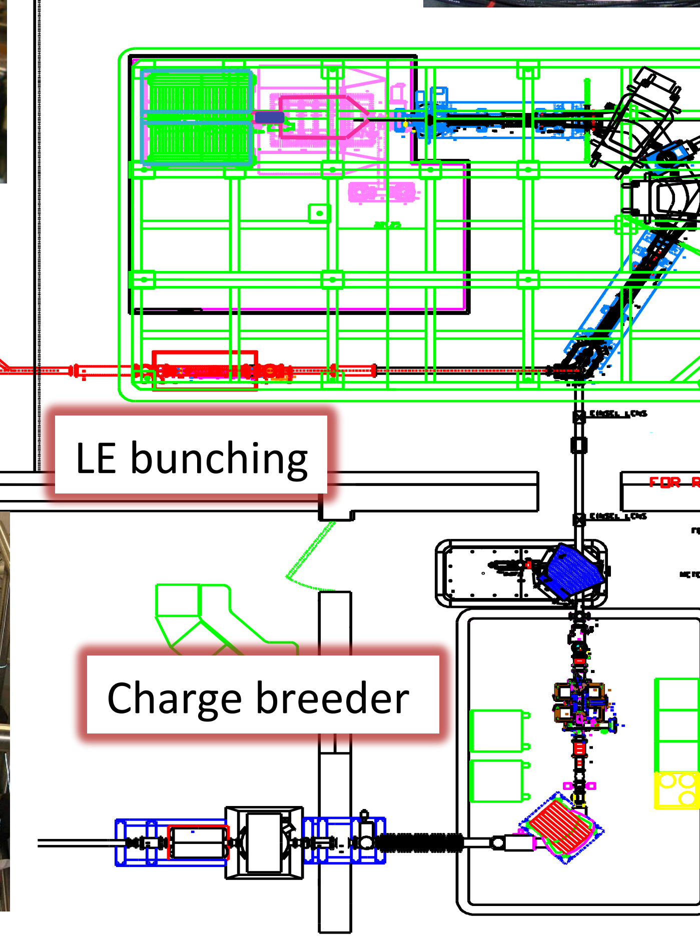
CARIBU – 1Ci ^{252}Cf source





1C of ^{252}Cf - 1.9 mg material deposited on a ~2 cm disk

- ✓ FP thermalization
- ✓ quick FP extraction – 5-20 ms with high efficiency -45%
- ✓ form a low-emittance beam for post-acceleration



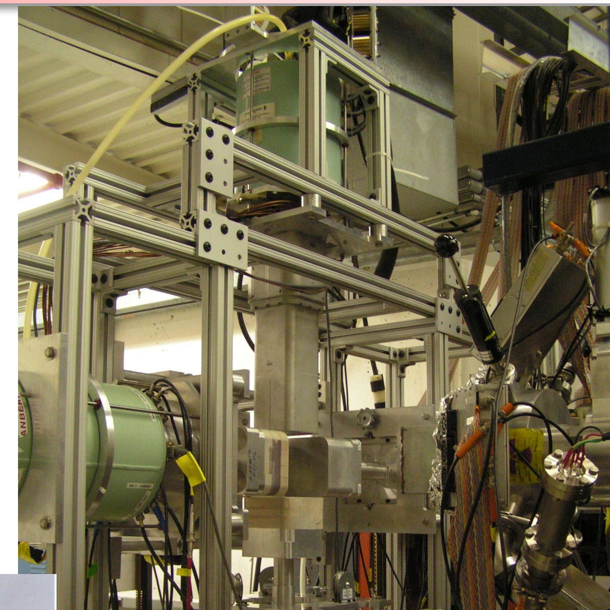
LE bunching

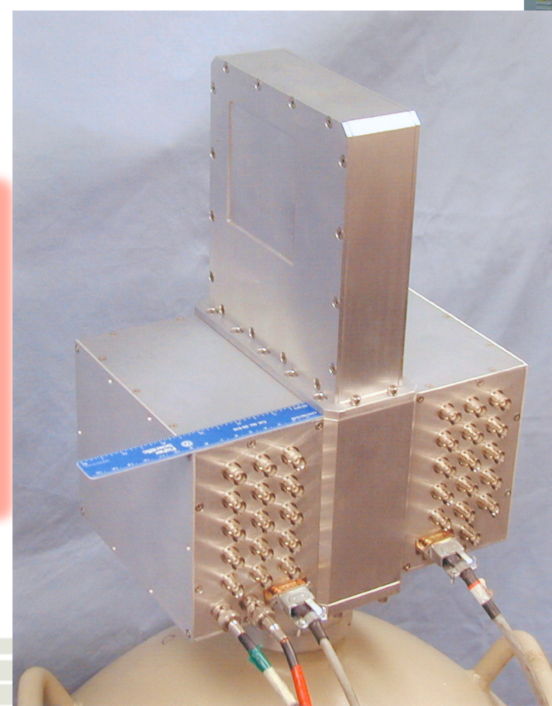
Charge breeder

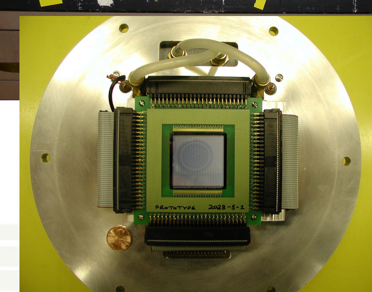
purifying the beam
$\Delta M/M \sim 1/20000$

Detector counting labs at ANL

- germanium detectors – many single Ge, LEPS, CLOVERS, DSSD – various size, high efficiency and energy resolution
- Si detectors (including DSSD) and PIPS (passivated implanted planar silicon) – mostly used for CE or β particles, but also for p and α−decay studies
- plastic scintillators, La_2Br_3 etc.

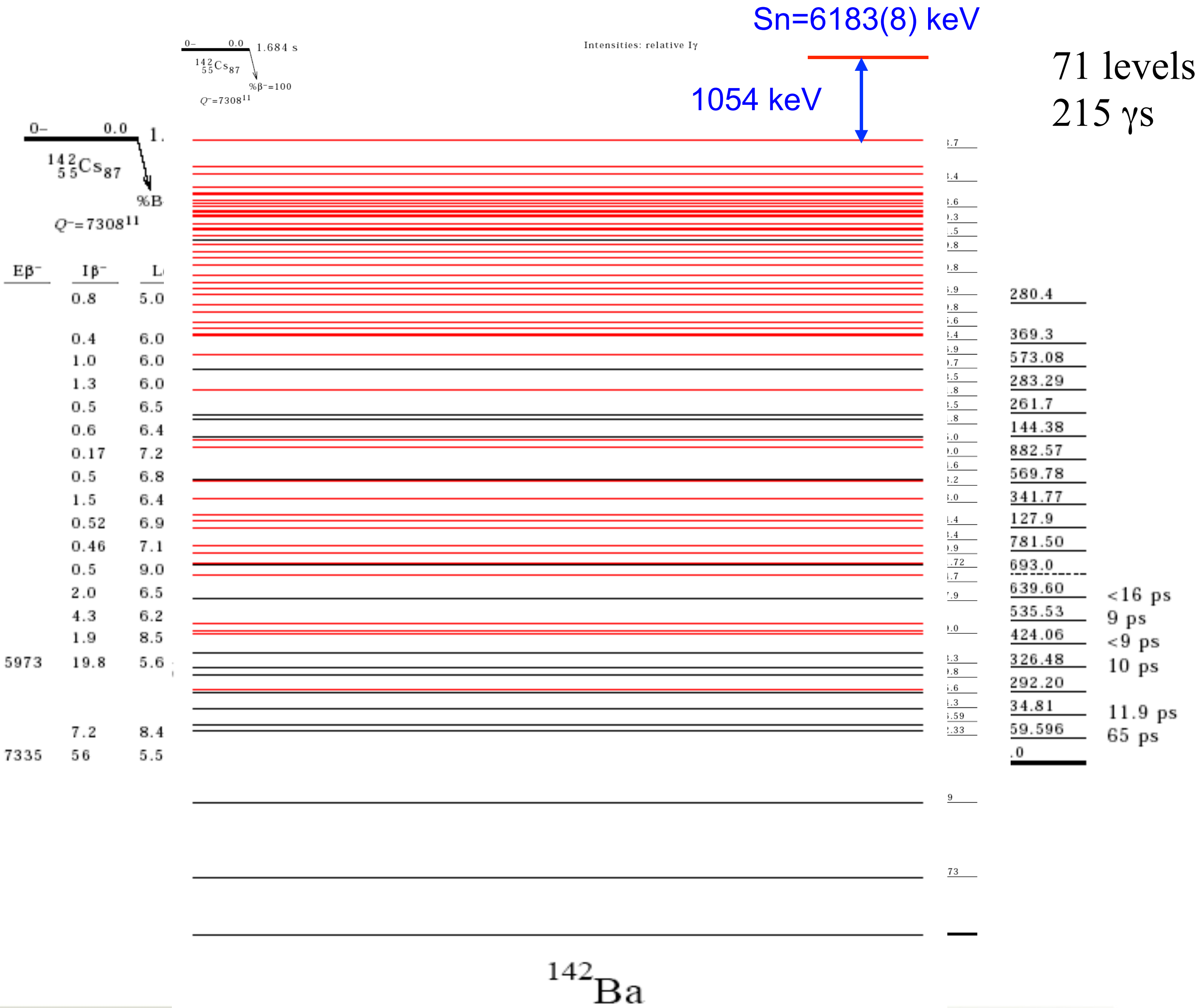






Capabilities to carry out precise measurements of relevance to medical isotopes research using a variety of techniques and detector equipment

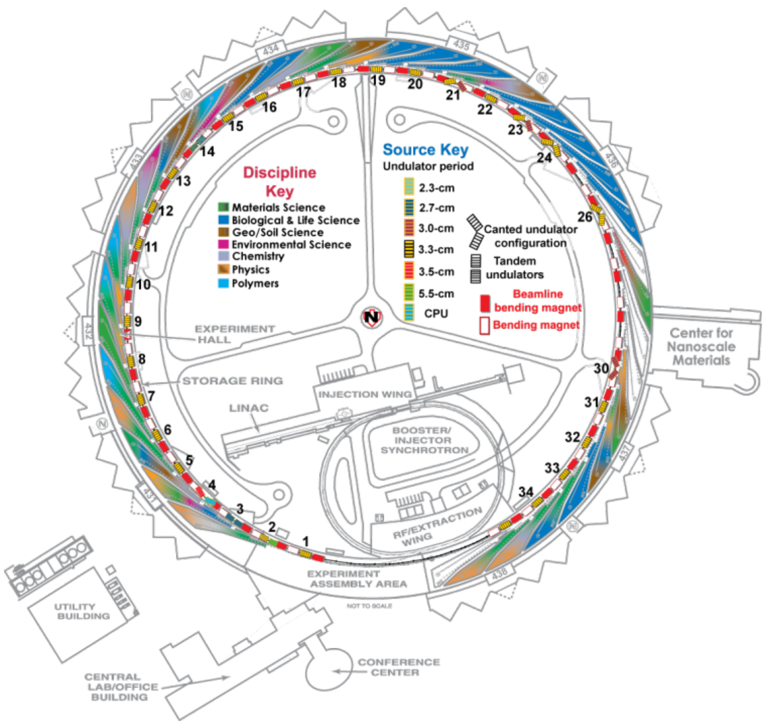
First decay schemes from CARIBU Ions



Data from Shaofei Zhu (PHY)

Advanced Photon Source

- The largest user facility in the US which accommodates 3500 users per year
  - 483 staff, including 75 technicians
- A 7 GeV electron accelerator which produces the brightest x-ray beams in the Western Hemisphere



ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Applied Radiation and Isotopes 65 (2007) 335–340
Applied Radiation and Isotopes

Measurements of the half-life of ^{246}Cm and the α-decay emission probabilities of ^{246}Cm and ^{250}Cf

F.G. Kondev[a,*], I. Ahmad[b], J.P. Greene[b], M.A. Kellett[c], A.L. Nichols[c]

Measurements of X- and γ-ray emission probabilities in the β^- decay of ^{233}Pa

F.G. Kondev[a,*], I. Ahmad[b], J.P. Greene[b], M.A. Kellett[c], A.L. Nichols[c,1]

ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 579 (2007) 458–460
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Measurement of the ^{240}Pu half-life

I. Ahmad[a,*], F.G. Kondev[a], J.P. Greene[a], M.A. Kellett[b], A.L. Nichols[b]

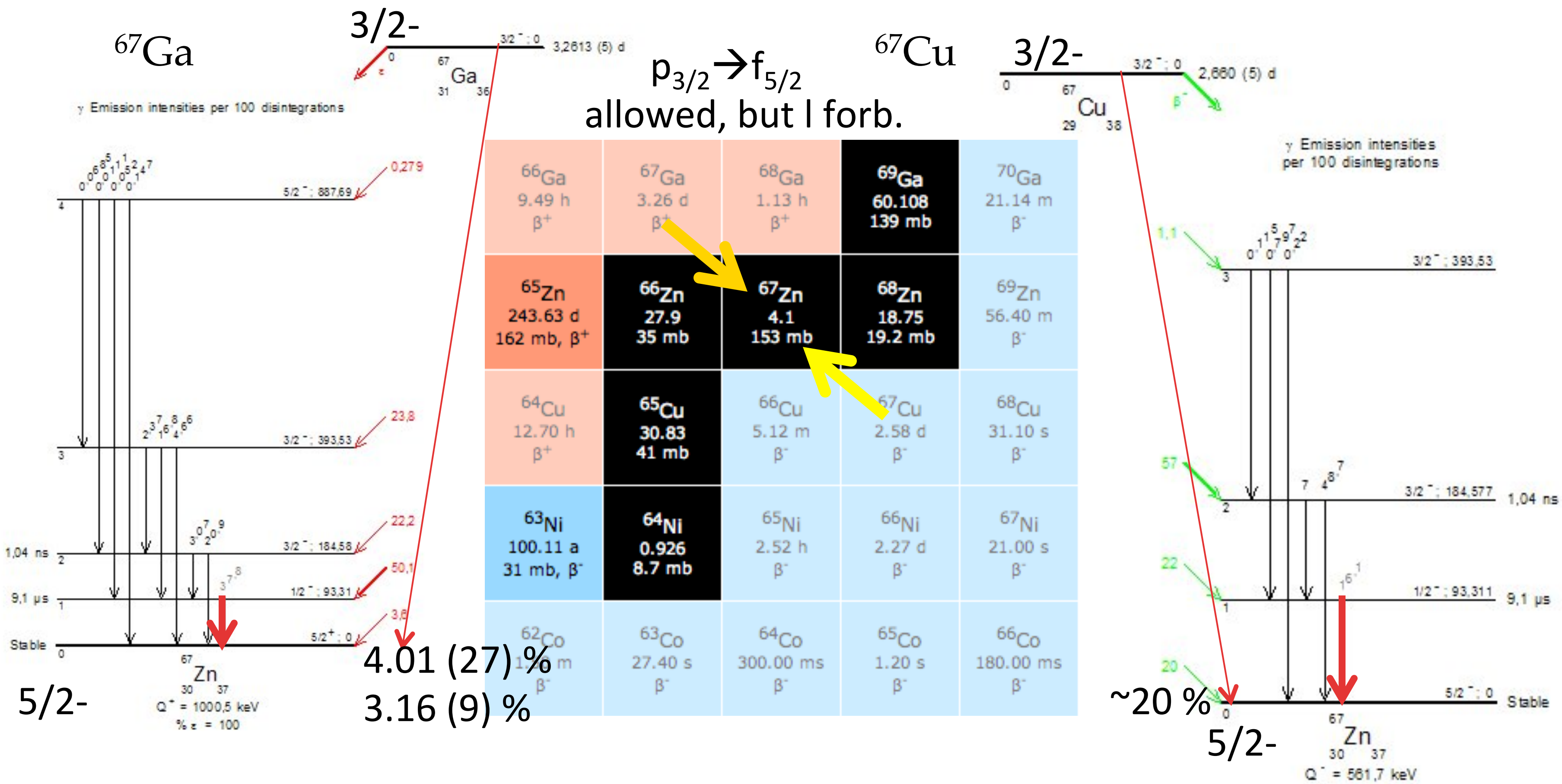
ND2007
International Conference on Nuclear Data for Science and Technology 2007
DOI: 10.1051/ndata:07241

Experimental studies to improve specific actinide decay data

F.G. Kondev[1,a], M.A. Kellett[2], I. Ahmad[3], J.P. Greene[3], and A.L. Nichols[2]

[1] Nuclear Engineering Division, Argonne National Laboratory, Argonne, IL 60439, USA
[2] Nuclear Data Section, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, 1400 Vienna, Austria
[3] Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA

^{67}Cu and ^{67}Ga examples



93 keV	ToI	ENSDF	NuDat	DDEP
^{67}Ga	39.2 (10)	38.81 (3) (0.9 (9) %)	38.81 (3)	38.1 (7) (3.6 (20) %)
^{67}Cu	16.1 (2)	16.1 (2) (~20 %)	16.1 (2) **20(2) %**	-

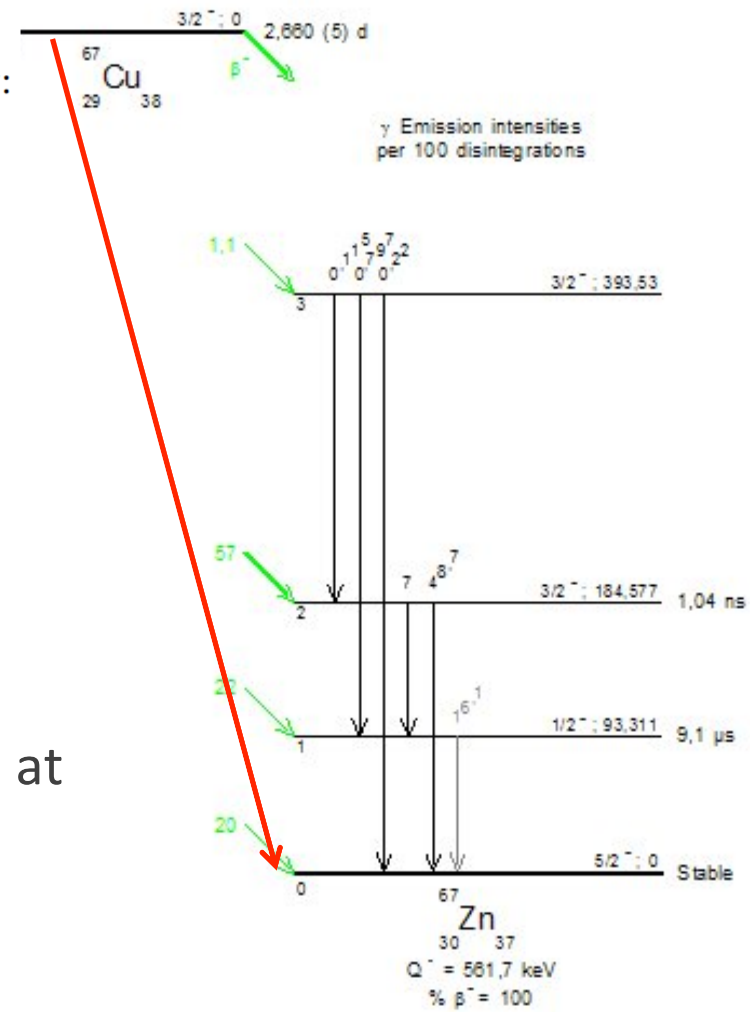
^{67}Cu example – cont.

Applied Radiation and Isotopes 70 (2012) 2377–2383

Review

The production, separation, and use of ^{67}Cu for radioimmunotherapy: A review

Nicholas A. Smith [a,*], Delbert L. Bowers [a], David A. Ehst [b]

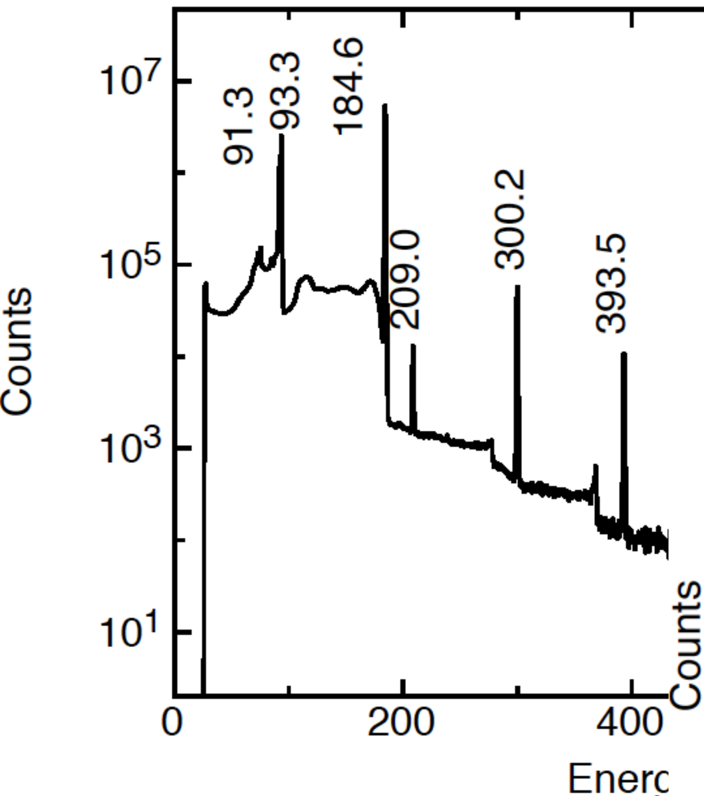


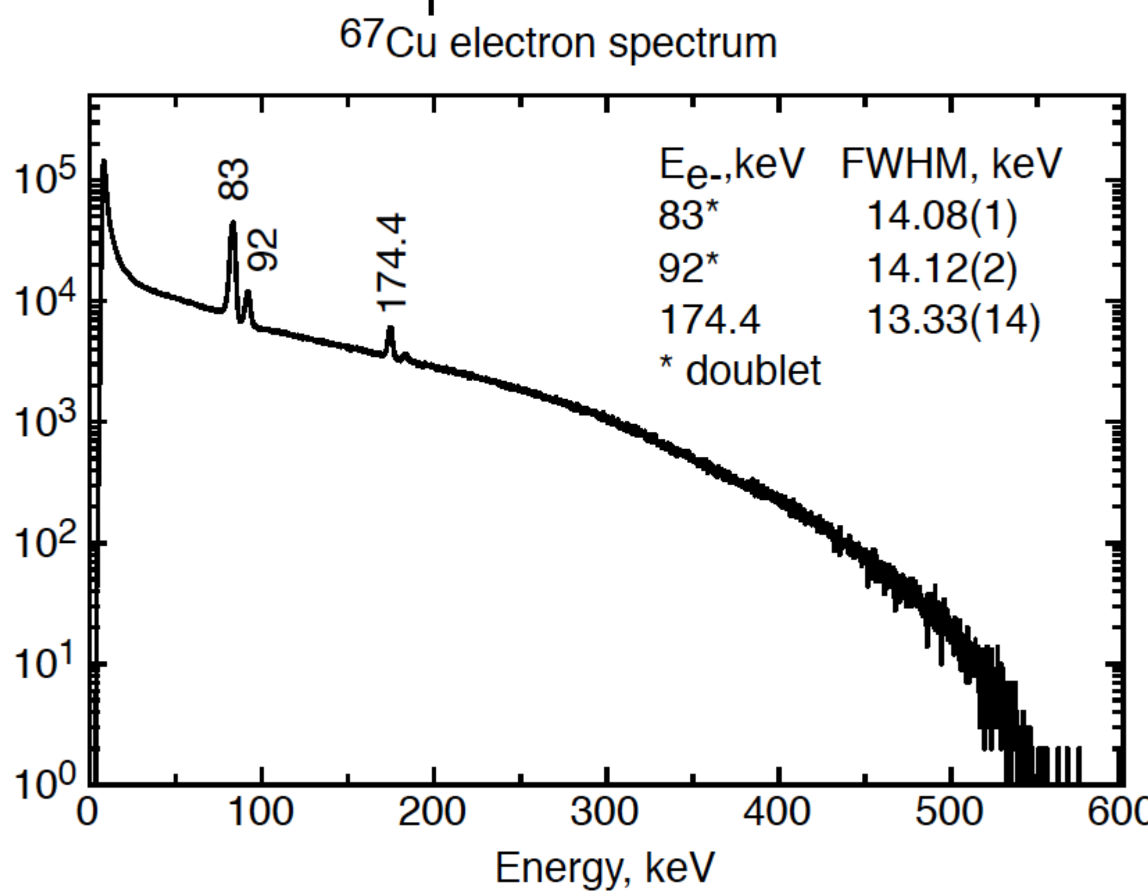
Studies at ANL:

- ✓ source produced using ^{68}Zn(γ,p) @ RPI; 40 MeV electron accelerator
- ✓ radiochemistry purification at ANL-CHEM
- ✓ singles (γ and β) measurements at ANL-NE(PHY)
- ✓ βγ coin measurements and βγ correlations at ANL-NE/PHY – next week

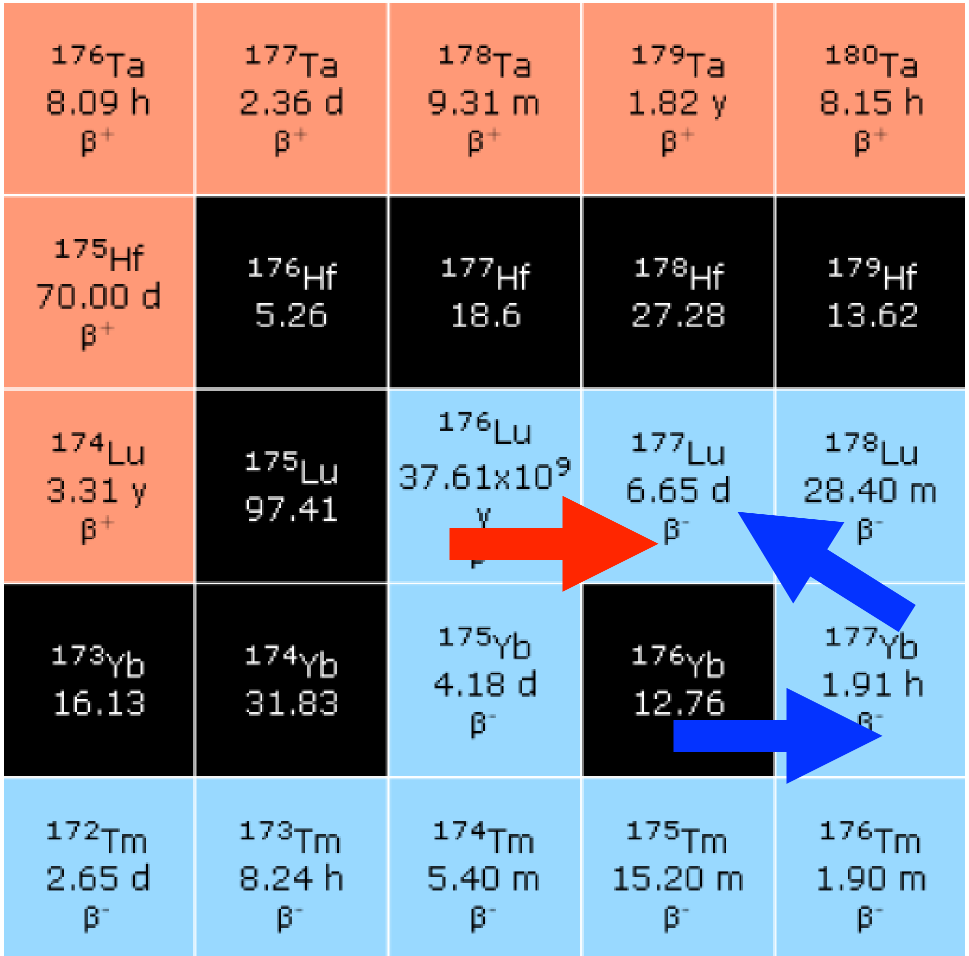
^{67}Cu example – cont.

1mm thick Si detector





Production of ^{177}Lu - impurities



^{176}Lu (n,γ): σ(n,γ)=2090 (70) b

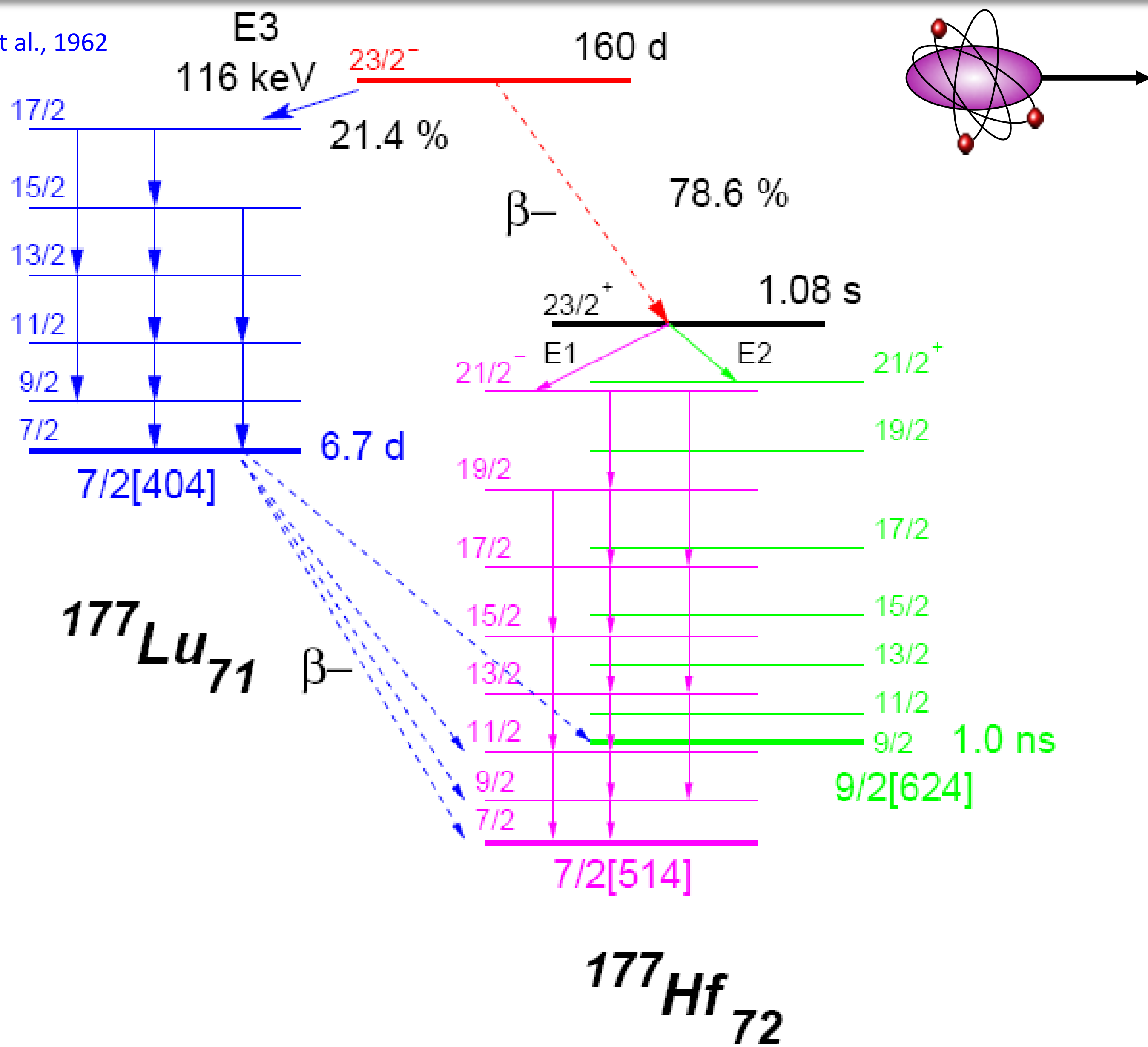
- ✓ large production CS
- ✓ but be aware of potential complications from ^{177m}Lu

^{176}Yb (n,γ): σ(n,γ)=3.02 (5) b

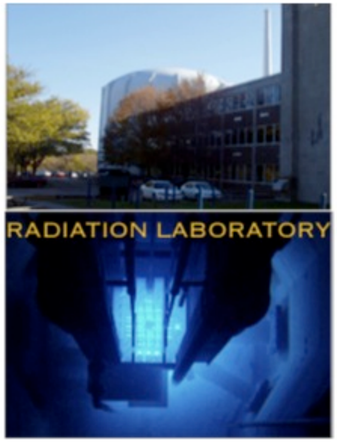
- ✓ small production CS
- ✓ no contaminants from ^{177m}Lu

Isomer population in ^{177}Lu

discovered by M. Jorgensen et al., 1962



Isomer production



$^{176}Lu(n,\gamma)^{177m}Lu$ @ UML

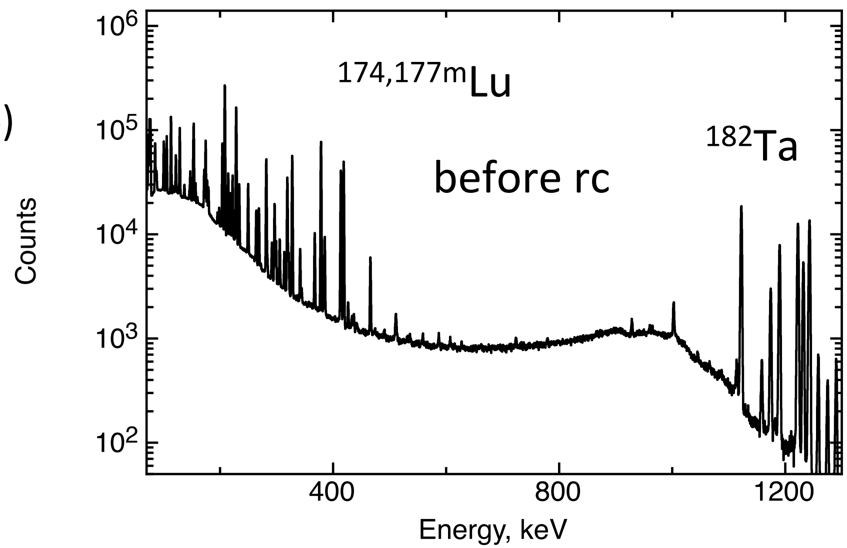
- ✓ natural Lu target material
- ✓ irradiation (4/24/2003 – 4/18/2006)
- ✓ total neutron fluence: 3.5×10^{19}
- ✓ ~4 yr of cooling

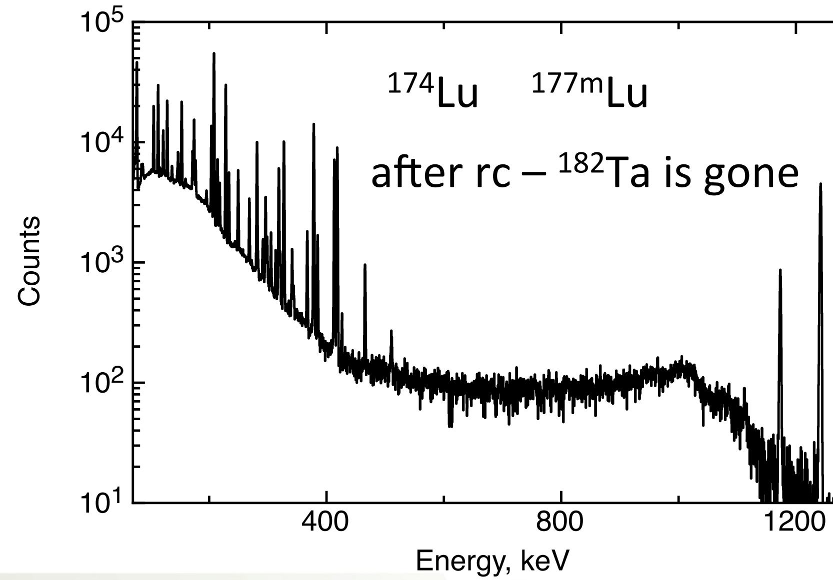
177W 132 M ε: 100.00%	178W 21.6 D ε: 100.00%	179W 37.05 M ε: 100.00%	180W 1.8E+18 Y 0.12% α: 100.00%	181W 121.2 D ε: 100.00%	182W >8.3E+18 Y 26.50% α	183W >1.3E+19 Y 14.31% α	184W >2.9E+19 Y 30.64% α
176Ta 8.09 H ε: 100.00%	177Ta 56.56 H ε: 100.00%	178Ta 9.31 M ε: 100.00%	179Ta 1.82 Y ε: 100.00%	180Ta 8.154 H ε: 86.00% β-: 14.00%	181Ta STABLE 99.988%	182Ta 114.43 D β-: 100.00%	183Ta 5.1 D β-: 100.00%
175Hf 70 D ε: 100.00%	176Hf STABLE 5.26%	177Hf STABLE 18.60%	178Hf STABLE 27.28%	179Hf STABLE 13.62%	180Hf STABLE 35.08%	181Hf 42.39 D β-: 100.00%	182Hf 8.90E+6 Y β-: 100.00%
174Lu 3.31 Y ε: 100.00%	175Lu STABLE 97.41%	176Lu 3.76E+10 Y 2.59% β-: 100.00%	177Lu 6.647 D β-: 100.00%	178Lu 28.4 M β-: 100.00%	179Lu 4.59 H β-: 100.00%	180Lu 5.7 M β-: 100.00%	181Lu 3.5 M β-: 100.00%

$^{181}Ta(n,\gamma)^{182}Ta$ - impurities

radiochemical separation

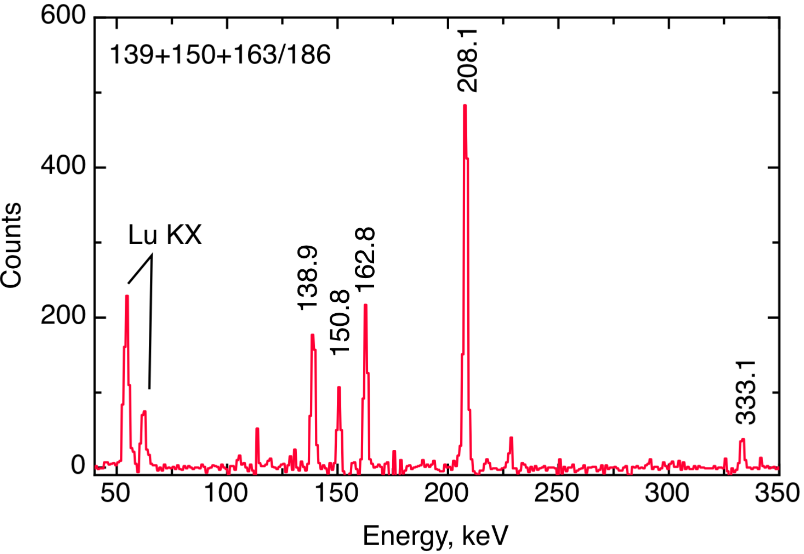
a single HpGe detector

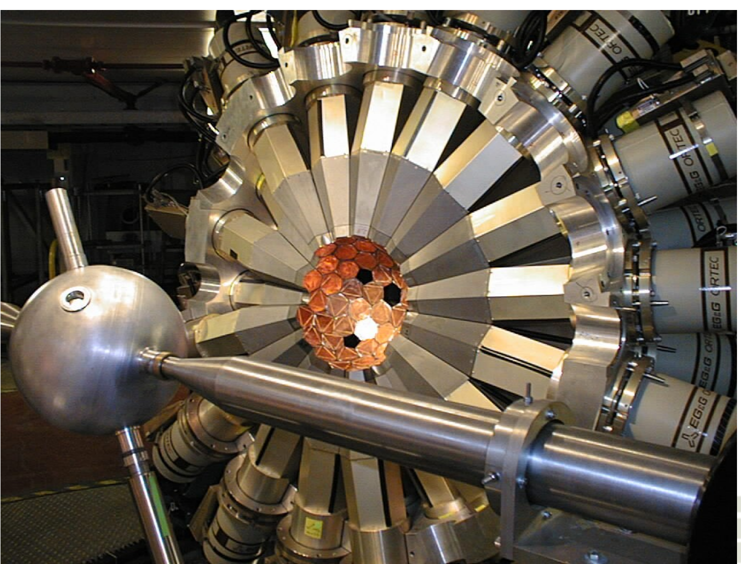


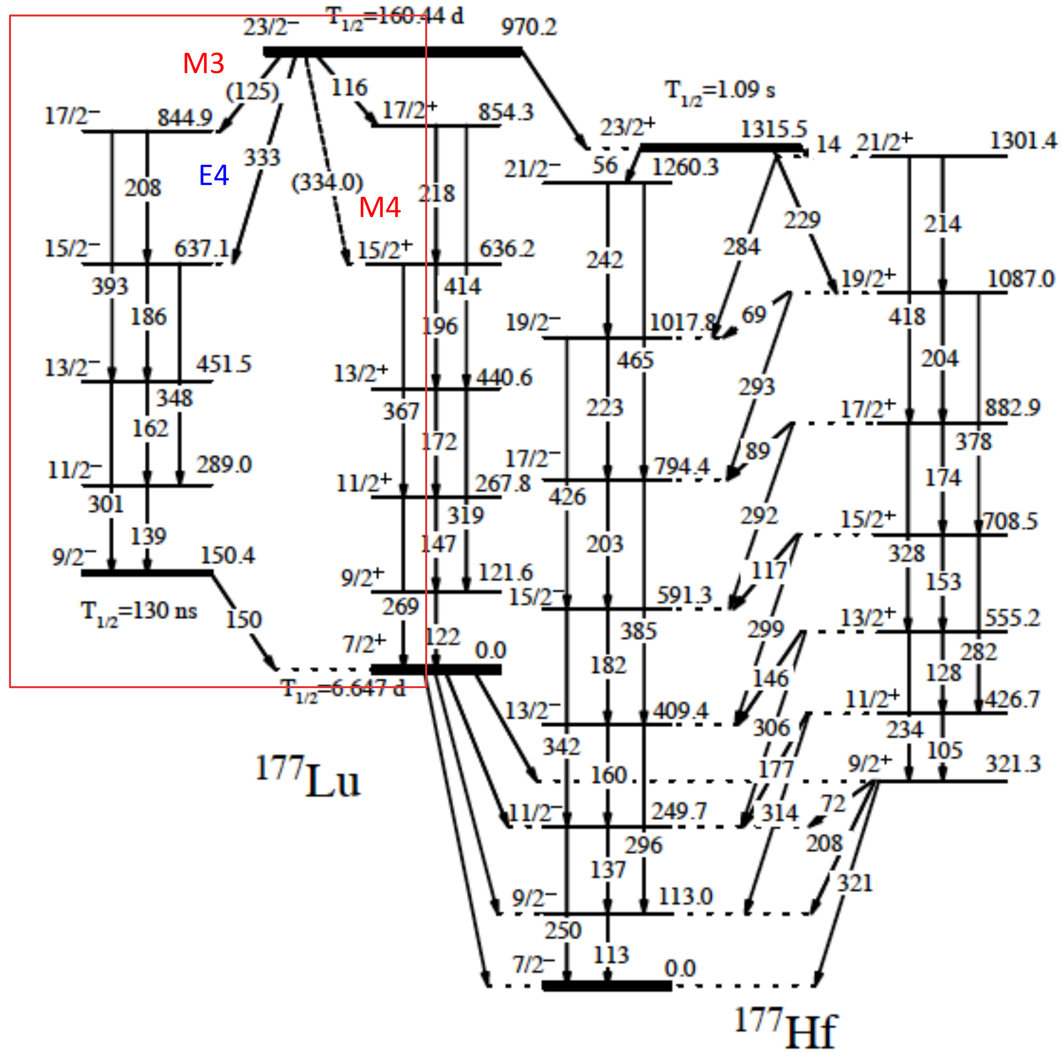


$K^{\pi}=23/2^{-}$ isomer in ^{177}Lu – cont.

$\alpha_T(M3)=94$ - $\alpha_T(E4)=1$

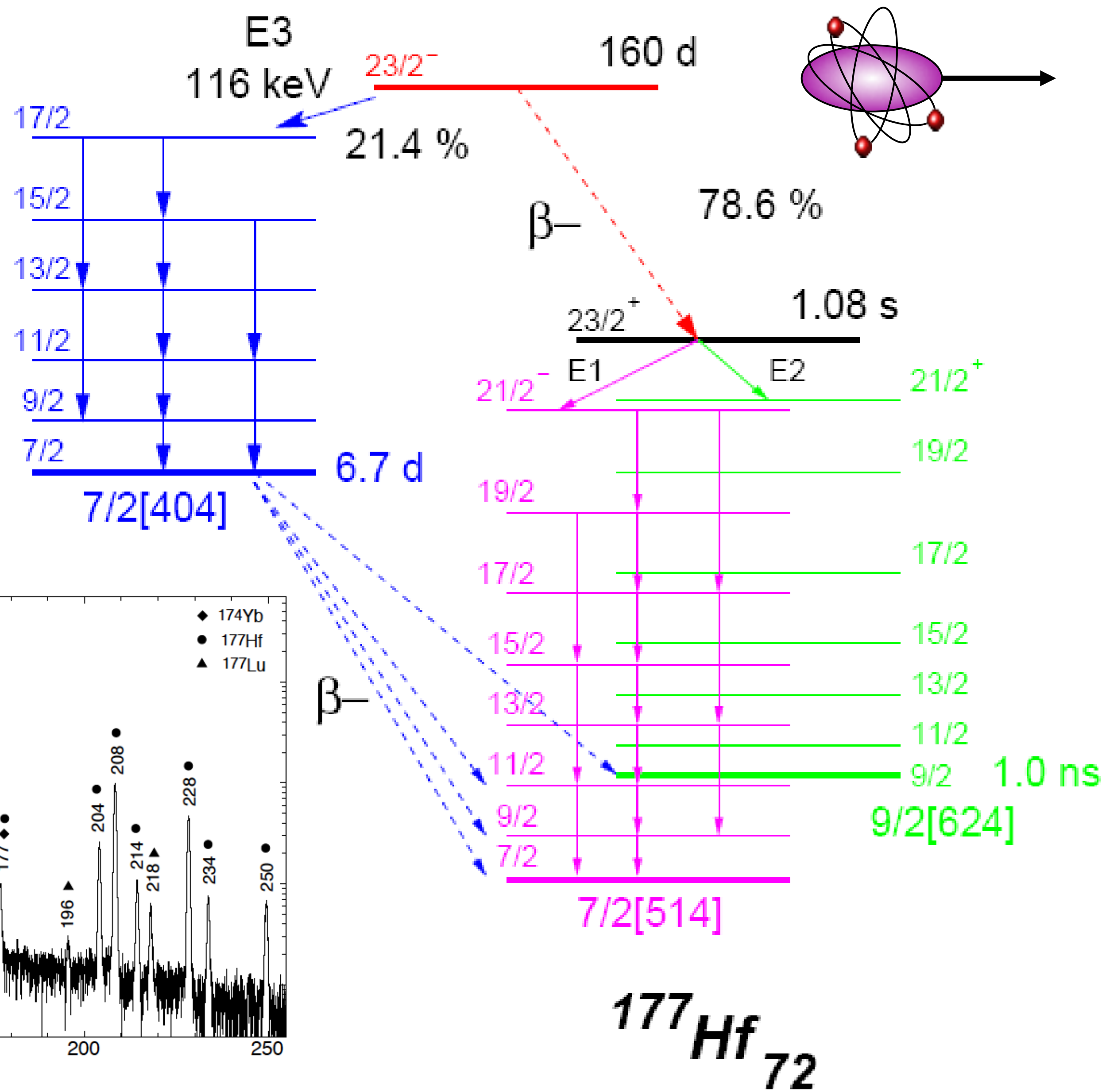




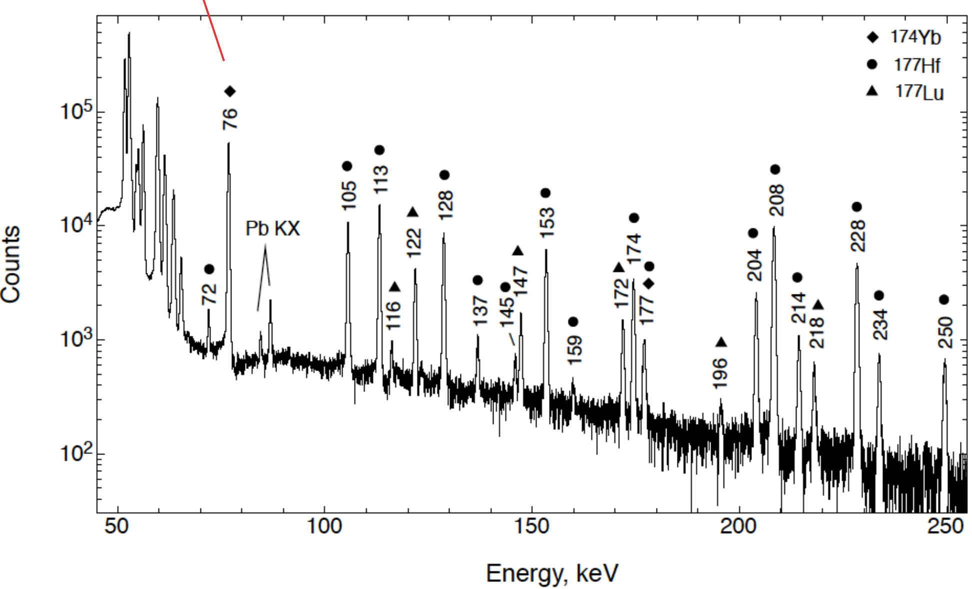


Branching Ratios

IT/β− - 10% different than previously evaluated!



not only ^{177m}Lu, but also ^{174}Lu from $^{175}Lu(n,2n)$



PHYSICAL REVIEW C **85**, 027304 (2012)

$M3$ and $E4$ K-forbidden decays of the $K^{\pi} = 23/2^{-}$ isomer in ^{177}Lu

F. G. Kondev,[1] S. Zhu,[1] M. P. Carpenter,[1] R. V. F. Janssens,[1] I. Ahmad,[1] C. J. Chiara,[1,2] J. P. Greene,[1] T. Lauritsen,[1] D. Seweryniak,[1] S. Lalkovski,[3] and P. Chowdhury[4]

ELSEVIER

Contents lists available at SciVerse ScienceDirect

Applied Radiation and Isotopes

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

Gamma-ray emission probabilities in the decay of ^{177m}Lu

F.G. Kondev [a,*], I. Ahmad [b], M.P. Carpenter [b], J.P. Greene [b], R.V.F. Janssens [b], T. Lauritsen [b], D. Seweryniak [b], S. Zhu [b], S.P. Lalkovski [c], P. Chowdhury [d]

ELSEVIER

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

γ–ray coincidence and fast-timing measurements using $LaBr_3$(Ce) detectors and gammasphere ☆

S. Zhu [a,*], F.G. Kondev [a], M.P. Carpenter [a], I. Ahmad [a], C.J. Chiara [a,b], J.P. Greene [a], G. Gurdal [a], R.V.F. Janssens [a], S. Lalkovski [c], T. Lauritsen [a], D. Seweryniak [a]

Measurements of relevance to this CRP

Priority I - INDC(NDS)-0591

^{66}Ga – production via $^{66}Zn(p,n)$@12 MeV

possibly

^{86}Y – production via $^{86}Sr(p,n)$@10-15 MeV

not of direct relevance -> will complete

^{67}Cu and initiate a new measurement program at APS – Nuclear Data needs for Auger emissions

Nuclear Decay Data Evaluation

- ENSDF evaluations
- AME & NUBASE evaluations
- XUNDL compilations
- IAEA-CRP on “Updated Decay Data Library for Actinides”
- DDEP “coordinator” – overseen the review process 2010-2012
- Development of atomic radiation database and corresponding computational infrastructure – in collaboration with T.Kibedi from ANU

ANL Region of Responsibility – cont.

- **21 mass chains permanently assigned to ANL:** A=176-179 and A=200-209

- new region of responsibility – closely related to our research interest

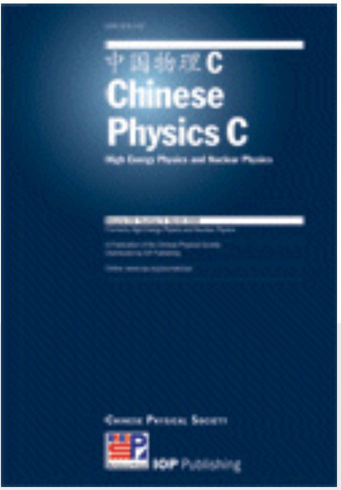
Mass Chain	NDS publication	Evaluator	Current Status
102	NDS **110** (2009) 1745	D. De Frenne	completed
103	NDS **110** (2009) 2081	D. De Frenne	completed
105	NDS **105** (2005) 775	D. De Frenne & E. Jacobs	completed
106	NDS **109** (2008) 943	D. De Frenne & A. Negret	completed
110	NDS **89** (2000) 481	D. De Frenne & E. Jacobs	**being evaluated**
112	NDS **79** (1996) 639	D. De Frenne & E. Jacobs	**being evaluated/****

** In collaboration with Prof. S. Lalkovski,Univ. Sofia

- **A=133** was published in collaboration with St. Petersburg group & work is continuing on **A=188** (with S. Juutinen, Jyvaskyla and D. Hartley, USNA) and **A=174** (with T. Kibedi, ANU and H. Xiaolong, CNDC)

AME2012 & NUBASE2012

Collaboration: **G. Audi** (CSNSM-Orsay), W. Mang (IMP-Lanzhou), F.G. Kondev (ANL-Argonne) & M. MacCormick (IPN-Orsay)



December 2012 issue of Chinese Physics **C** (IOP Science)

CPC(HEP & NP), 2012, **36**(12): 1157–1286 **Chinese Physics C** Vol. 36, No. 12, Dec., 2012

The NUBASE2012 evaluation of nuclear properties*

G. Audi[1,§], F.G. Kondev[2], M. Wang[1,3,4], B. Pfeiffer[5,‡], X. Sun[1], J. Blachot[1], and M. MacCormick[6]

The AME2012 atomic mass evaluation *

(I). Evaluation of input data, adjustment procedures

G. Audi[1,§], M. Wang[1,2,3], A.H. Wapstra[4,†], F.G. Kondev[5], M. MacCormick[6], X. Xu[2,7], and B. Pfeiffer[8,‡]

The AME2012 atomic mass evaluation *

(II). Tables, graphs and references

Evaluations
- AME
- NUBASE

AME + Nubase 2012
- Schedule
- Ask for reprint

Registration

http://ribll.impcas.ac.cn/ame/

Evaluations for the IAEA-CRP project

ANL: ^{66}Ga (priority 1) & ^{76}Rb (priority 3) -> ^{67}Cu

Will have another presentation on Thursday on technical details regarding decay data evaluation

Repository and dissemination –
IAEA-NDS Medical Portal must be the focal point!

What about the decay data that are needed for cross-section measurements? There are some common nuclides, but is re-evaluation needed for others?