Mass measurements along the rp–process path: Results of recent measurements

D. S. Brenner

Collaborators

Clark University

Bryan Tomlin
Victor Zamfir
Charles Barton
Alex Wolf

Brookhaven National Laboratory

Ron Gill

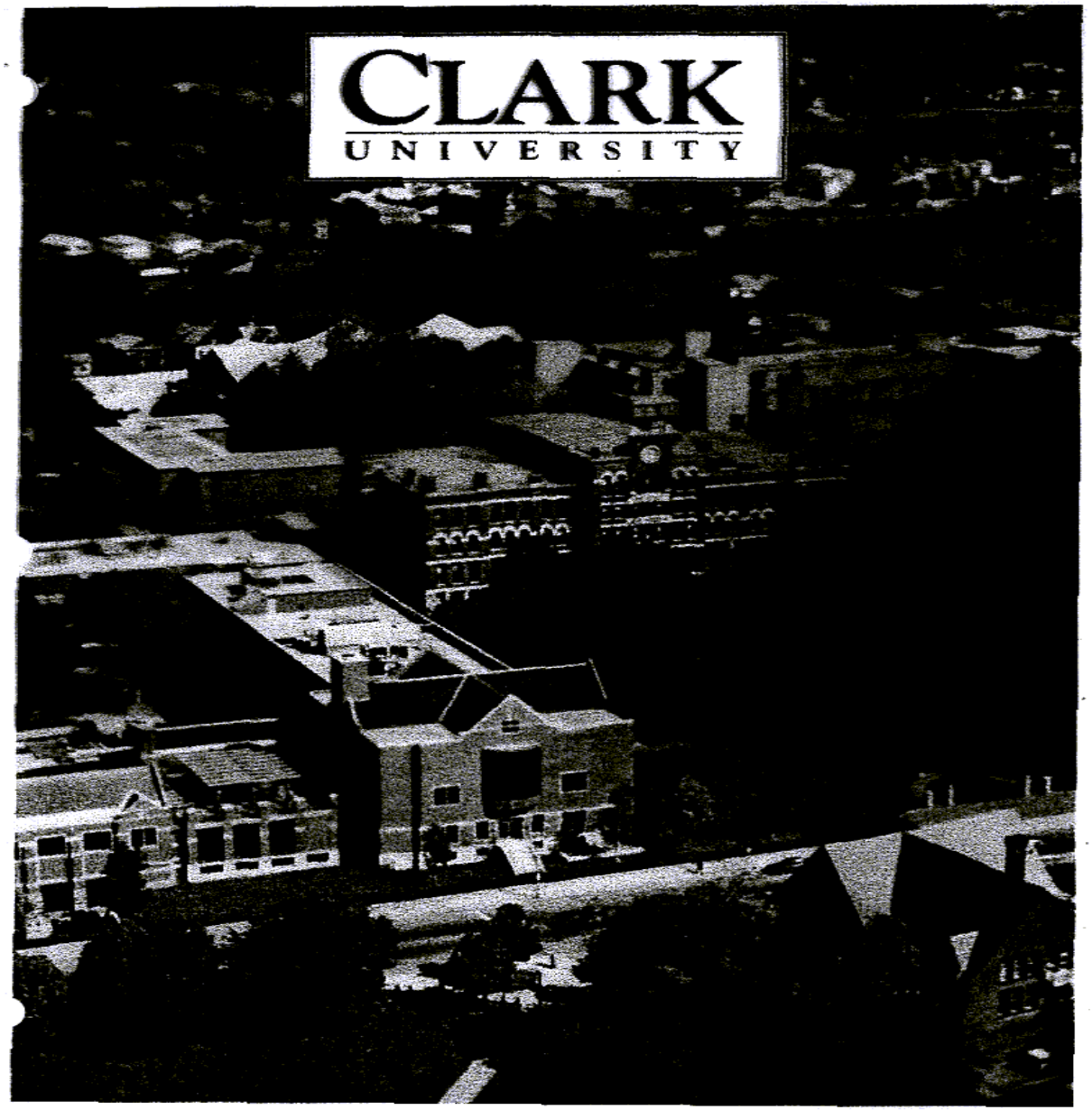
Yale University

Con Beausang
Mark Caprio
Rick Casten
Gheorghe Cata-Danil
Joakim Cederkall
Jeff Cooper
Adam Hecht
Reiner Krücken
Benyuan Liu
Heather Newman
John Novak
Zhijun Wang
Lissa Zyromski

Sponsorship

US Department of Energy

CLARK UNIVERSITY



Mass Measurements Along the rp-Process Path

- motivation for mass measurements far from stability
- accuracy of mass formulas far from stability
- experimental method
- results
- plans for future measurements at Yale
- acknowledgements

WHY MEASURE MASSES?

- the atomic mass is the ultimate synthesis of all nucleonic interactions

- masses provide indicators of structural change; two-nucleon separation energies signal shell closures and quadrupolar deformation

- experimental measurements test mass formulas used to predict properties of nuclei far from stability

- masses provide important input data for model calculations of stellar nucleosynthesis and the path of the rapid proton capture (rp) process

- masses provide useful data for planning experiments far from stability such as searches for proton decay radioactivity

Mass Formulas

- **APDT** **Y. Aboussir, J. M. Pearson, A. K. Dutta, and F. Tondeur, At. Data Nucl. Data Tables 61, 127 (1995).**

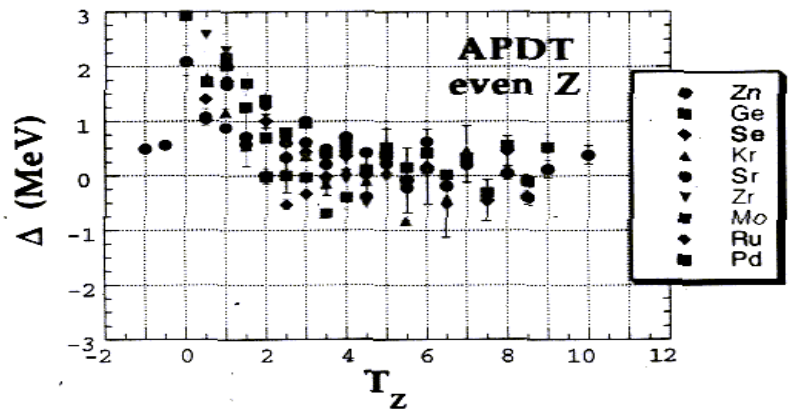
  microscopic model using the extended Thomas-Fermi plus Strutinsky integral method

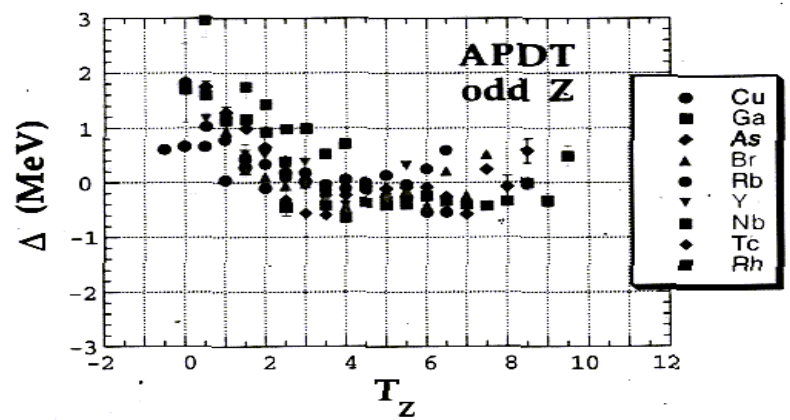
- **MNMS** **P. Möller, J. R. Nix, W. D. Myers, and W. J. Swiatecki, At. Data Nucl. Data Tables 59, 185 (1995).**

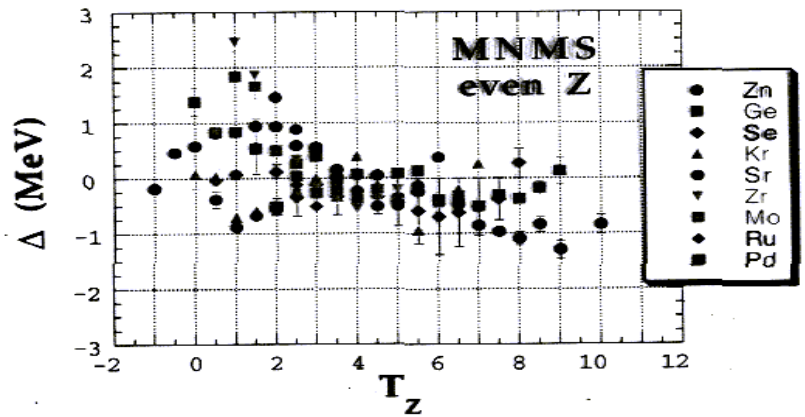
  finite-range droplet macroscopic/folded-Yukawa single particle microscopic model

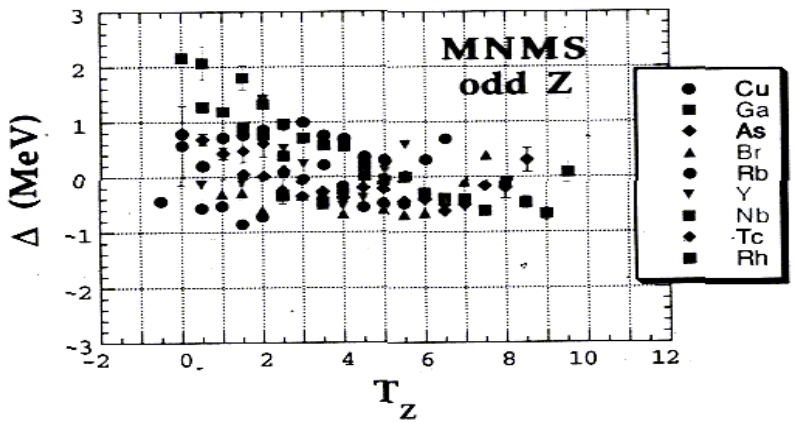
Mass Formula Systematics in the N,Z = 28-50 Shell Quadrant

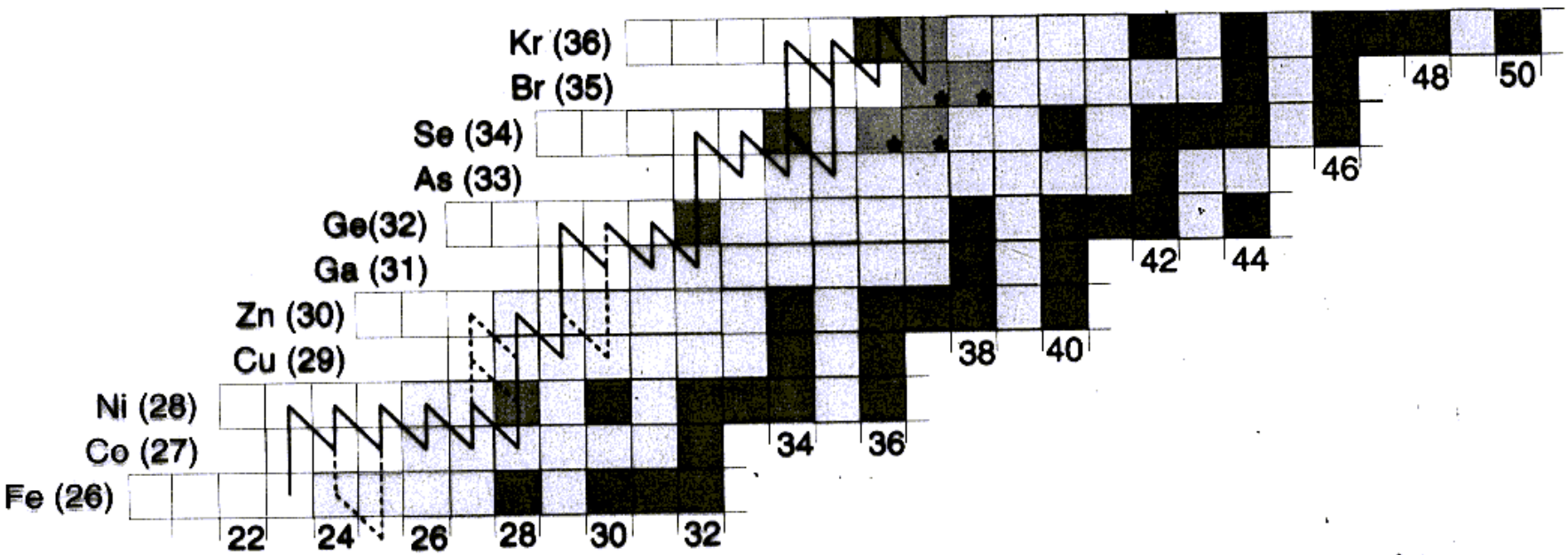
$$\Delta = (M\text{-}A)_{theory} - (M\text{-}A)_{experiment}$$






MNMS
even Z
Zn
Ge
Se
Kr
Sr
Zr
Mo
Ru
Pd
Δ (MeV)
T_Z


MNMS
odd Z
Cu
Ga
As
Br
Rb
Y
Nb
Tc
Rh
Δ (MeV)
T_Z



Δ(M–A) <100 keV

Δ(M–A) >100 keV

waiting point

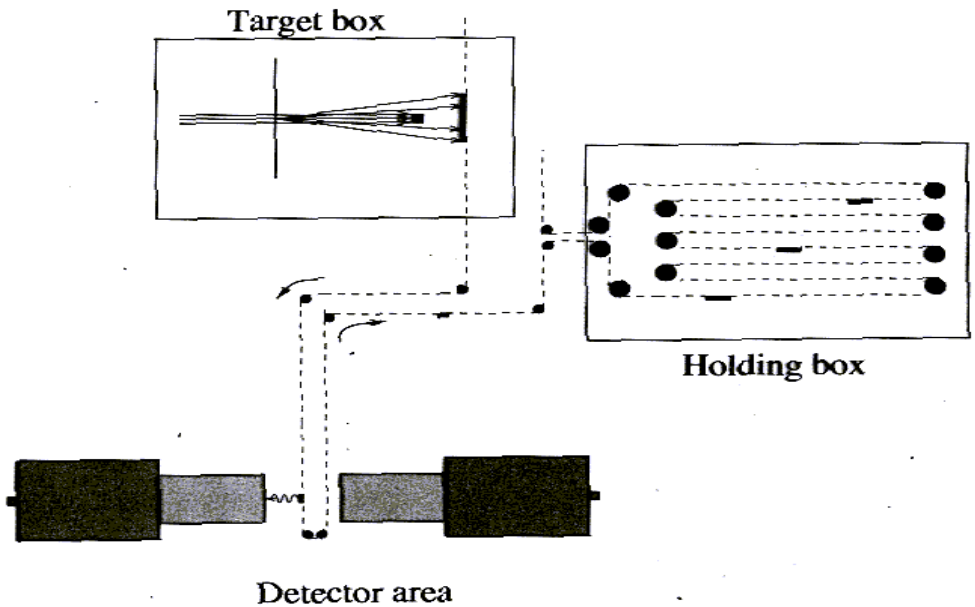
—— flux > 10%

..... flux 1 - 10%

Experimental Method

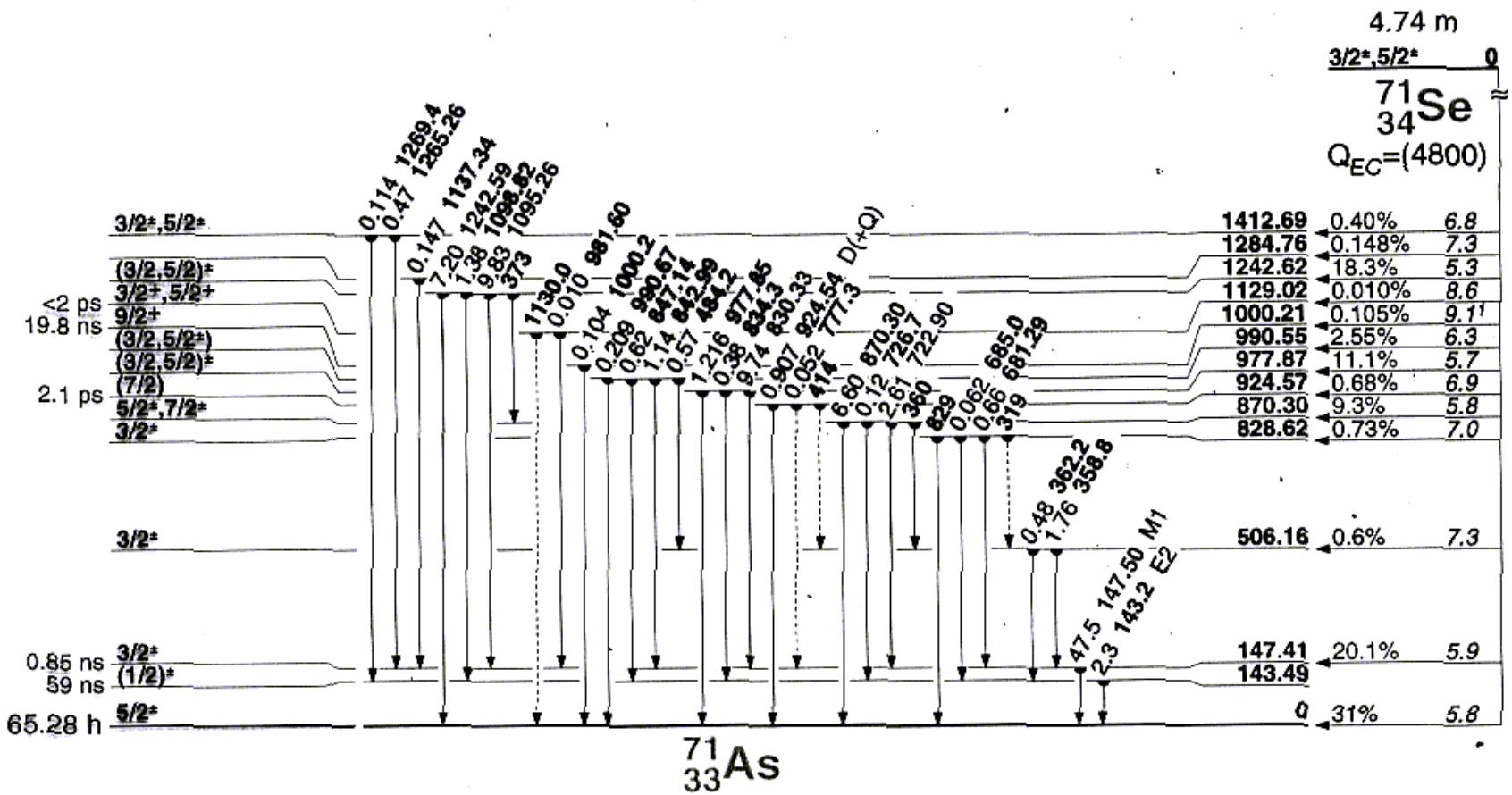
- ^{71}Se produced by ^{58}Ni(^{16}O,2pn) at Yale
- 4.74 min ^{71}Se activity was collected on an aluminized Kapton tape and transported to a shielded counting station
- β-γ coincidence spectroscopy was used to measure positron endpoint energies
- calibrations were made using β^+ spectrum endpoint measurements for well known nuclides: ^{67}Ge and ^{70}As
- effects of summing in the plastic scintillator β^+ detector were carefully scrutinized
- multiple pathways were used to establish Q_{EC}

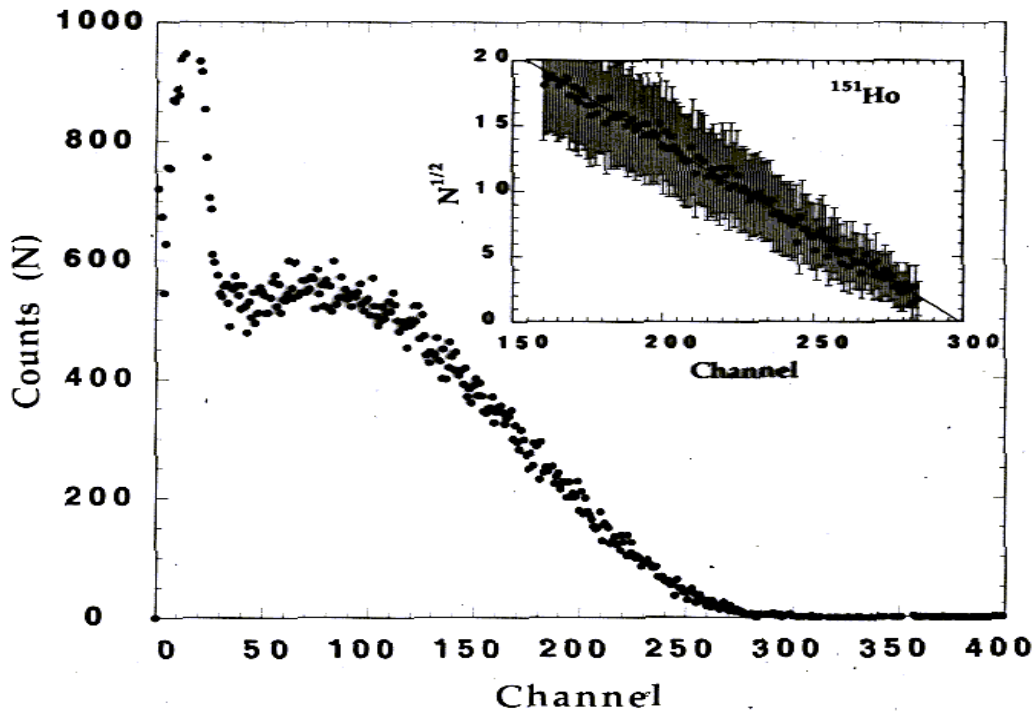
The Yale Moving Tape Collector



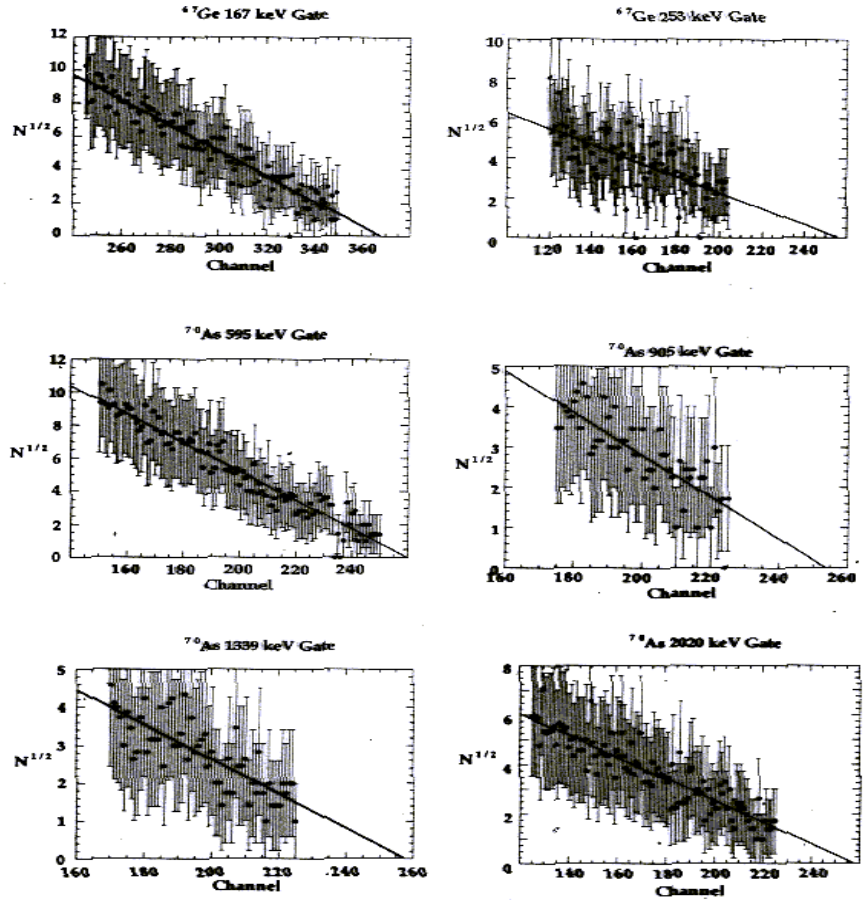
Deposition and spectroscopy in parallel
Product separation by optimizing time between tape advances to select half life of interest

^{71}Se Decay Scheme

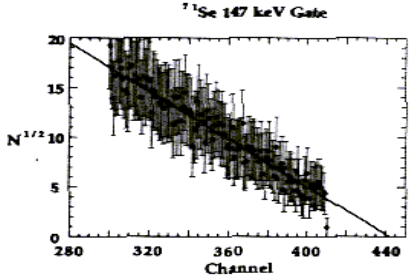


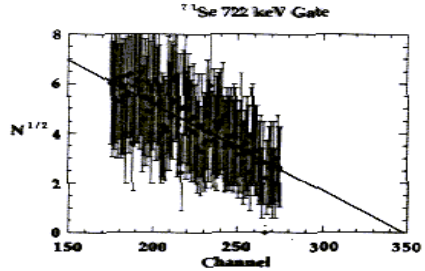

1000
800
600
400
200
0
Counts (N)
0
50
100
150
200
250
300
350
400
Channel
20
15
10
5
0
$N^{1/2}$
150
200
250
300
Channel
^{151}Ho

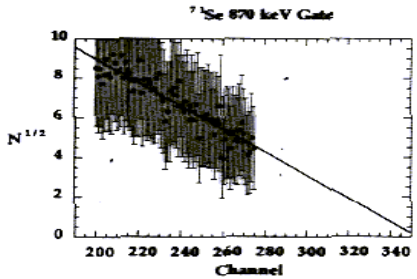
Calibrator Spectra

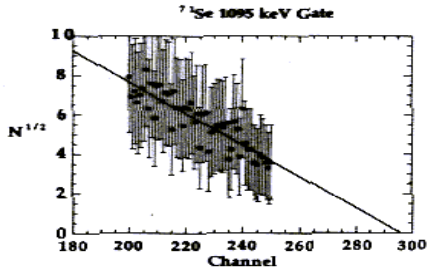


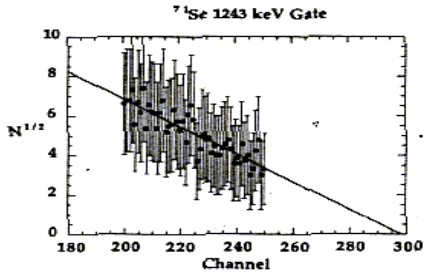
^{71}Se γ-Ray Gated β^{+} Spectra

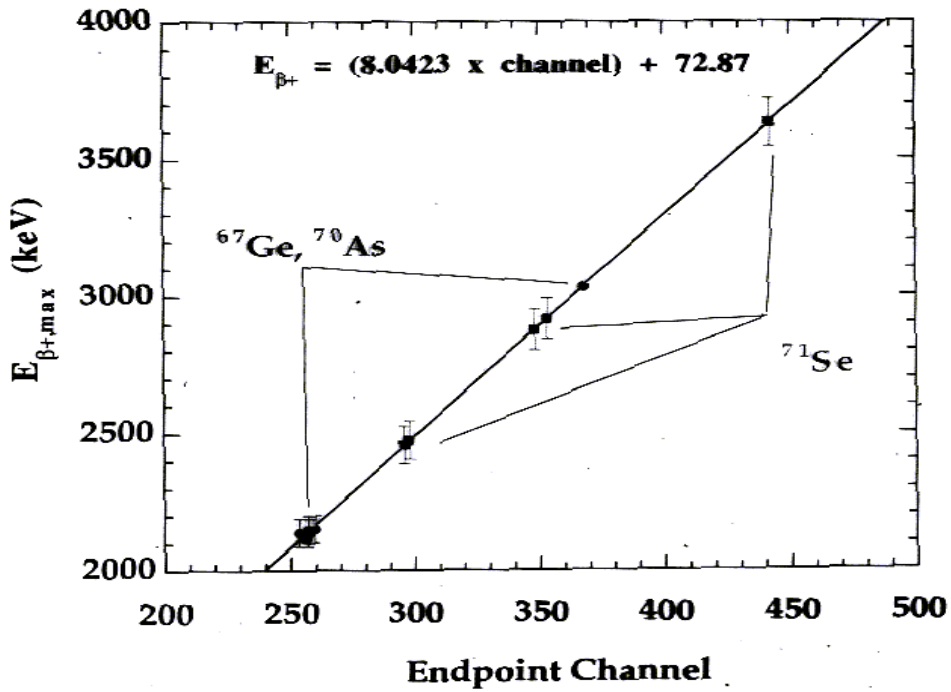











$E_{\beta+} = (8.0423 \times \text{channel}) + 72.87$
^{67}Ge, ^{70}As
^{71}Se
$E_{\beta+max}$ (keV)
Endpoint Channel
4000
3500
3000
2500
2000
200
250
300
350
400
450
500

β^+ Endpoint Energies and Q_{EC} Values (keV)

Nucleus	γ-ray gate	β^+ Endpoint Energy	Q_{EC}
^{71}Se	147	3630 (90)	4799 (90)
	723	2875 (75)	4767 (75)
	870	2915 (75)	4808 (75)
	1095	2455 (70)	4720 (70)
	1243	2473 (70)	4738 (70)
		(weighted mean)	4762 (35)

^{71}Se Mass Excess Values (keV)

Our Work	-63130 (35)
Nubase[a]	-63090 (200)
Chartier *et al.*[b]	-63490 (320)

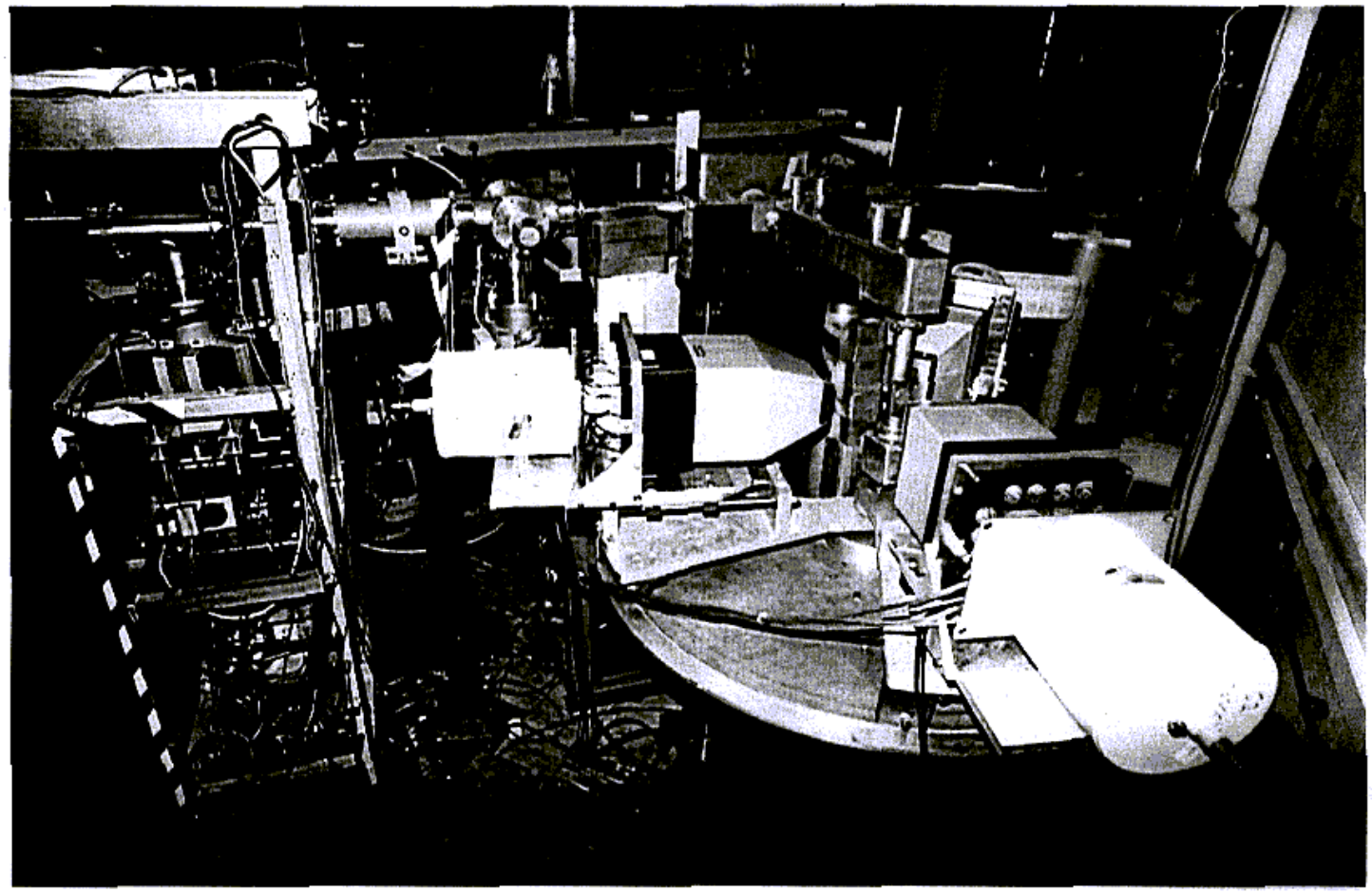
[a] G. Audi, O. Bersillon, J. Blachot, and A. H. Wapstra, Nucl. Phys. A624, 1 (1997). Values and uncertainties were estimated from systematic trends.

[b] M. Chartier, W. Mittig, N. A. Orr, J.-C Angélique, G. Audi, J.-M. Casandijian, A. Cunsolo, C. Donzaud, A. Foti, A. Lépine-Szily, M. Lewitowicz, S. Lukyanov, M. MacCormick, D. J. Morrissey, A. N. Ostrowski, B. M. Sherrill, C. Stephan, T. Suomijärvi, L. Tassan-Got, D. J. Vieira, A. C. C. Villari and J. M. Wouters, Nucl. Phys. A637, 3 (1998). The authors reported their uncertanties as ±250(syst.)±200(stat.) which we have added in quadrature to give ±320 keV.

Experimental Method

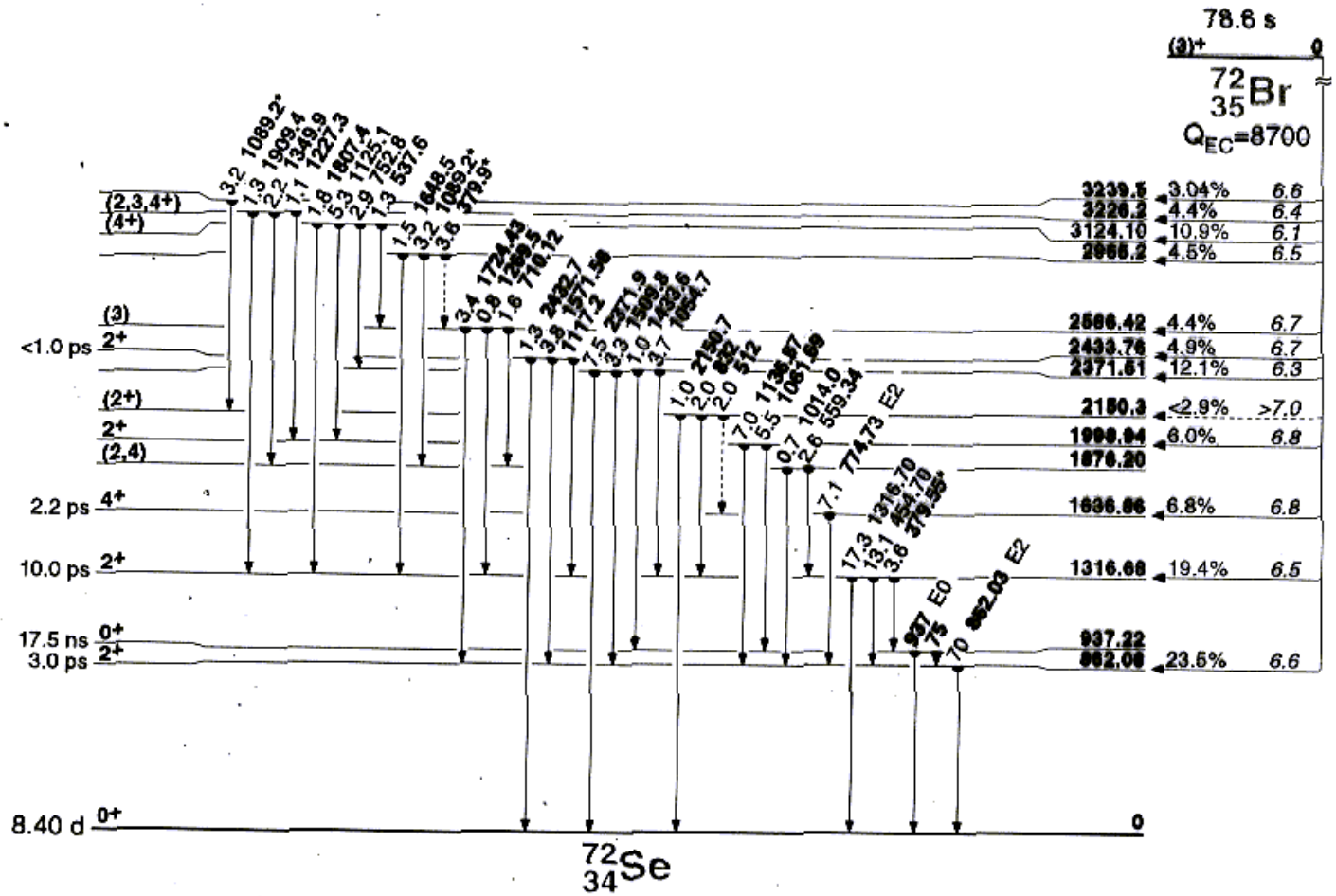
- ^{72}Br produced by ^{58}Ni(^{16}O,pn) at Yale
- 78.6 s ^{72}Br activity was collected on an aluminized Kapton tape and transported to a shielded counting station
- three state-of-the-art Compton-suppressed Ge clover γ-ray detectors were used to improve detection efficiency and selectivity
- calibrations were made using β^+ spectrum endpoint measurements for well known nuclides: ^{65}Ga, ^{67}Ge, ^{68}As, and ^{71}Se
- effects of summing in the plastic scintillator β^+ detector were carefully scrutinized
- multiple pathways were used to establish Q_{EC}

The Yale Moving Tape Collector

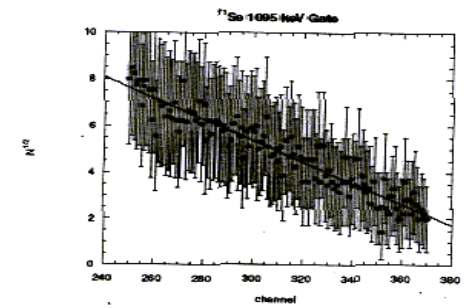


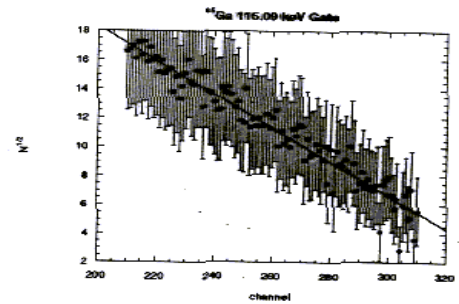
M. A. Caprio, WNSL, Yale University

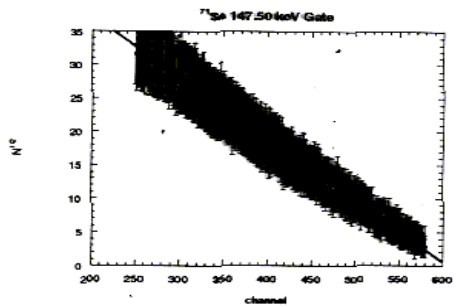
^{72}Br Decay Scheme

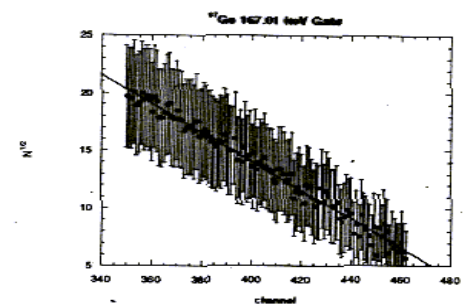


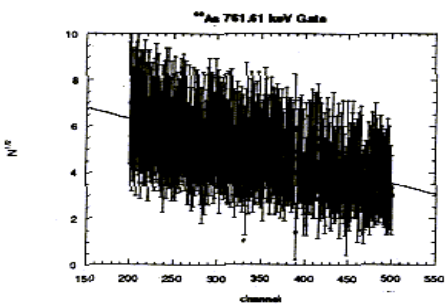
Calibrator Spectra

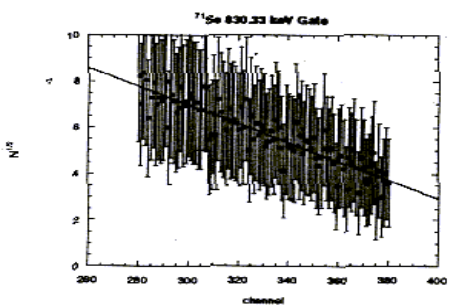


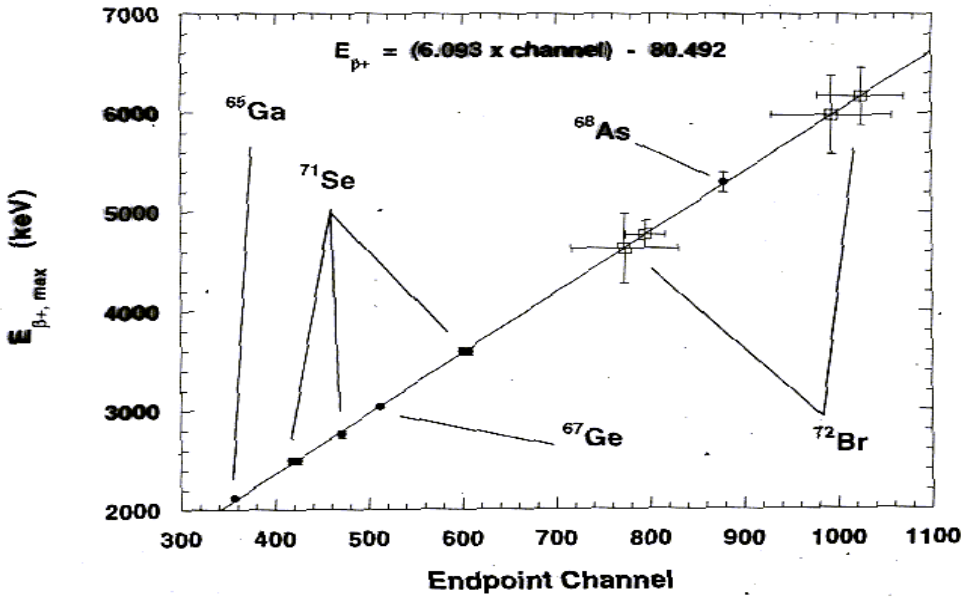











$E_{\beta+} = (6.093 \times \text{channel}) - 80.492$
^{65}Ga
^{71}Se
^{68}As
^{67}Ge
^{72}Br
$E_{\beta+,\,max}$ (keV)
Endpoint Channel
7000
6000
5000
4000
3000
2000
300
400
500
600
700
800
900
1000
1100

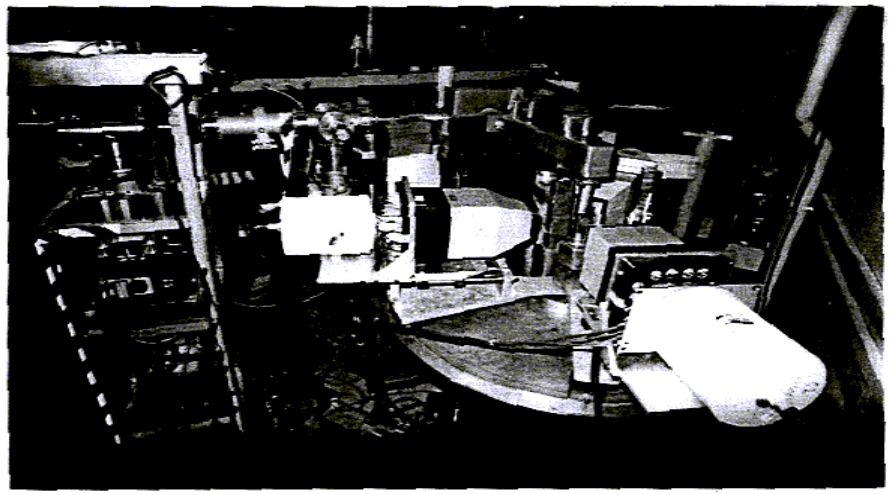
Summing Effects in the β^+ Detector

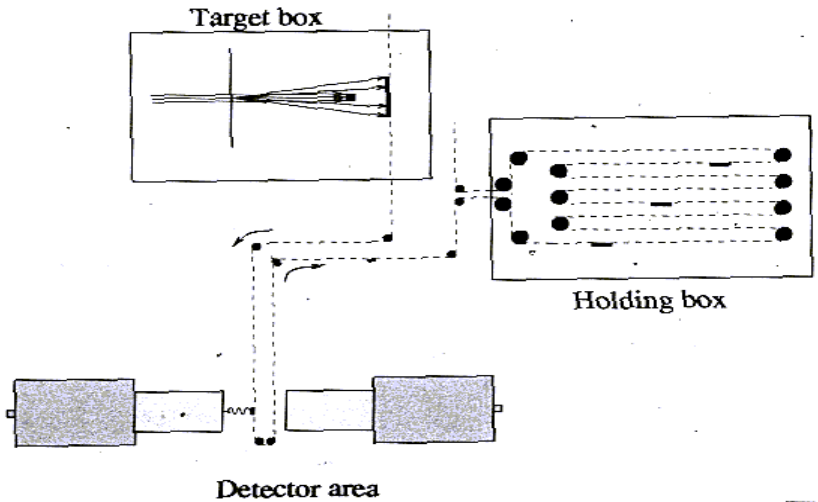
- **random summing**
  - --minimized if counting rates are low

- **decay scheme summing**
  - --function of the decay scheme
  - --minimized if there is a strong β^+ branch to a low lying level in the daughter

- **annihilation summing**
  - --always present
  - --systematically incorporated into the scintillator energy calibration curve

The Yale Moving Tape Collector





M. A. Caprio, WNSL, Yale University

β^+ Endpoint Energies and Q_{EC} Values (keV)

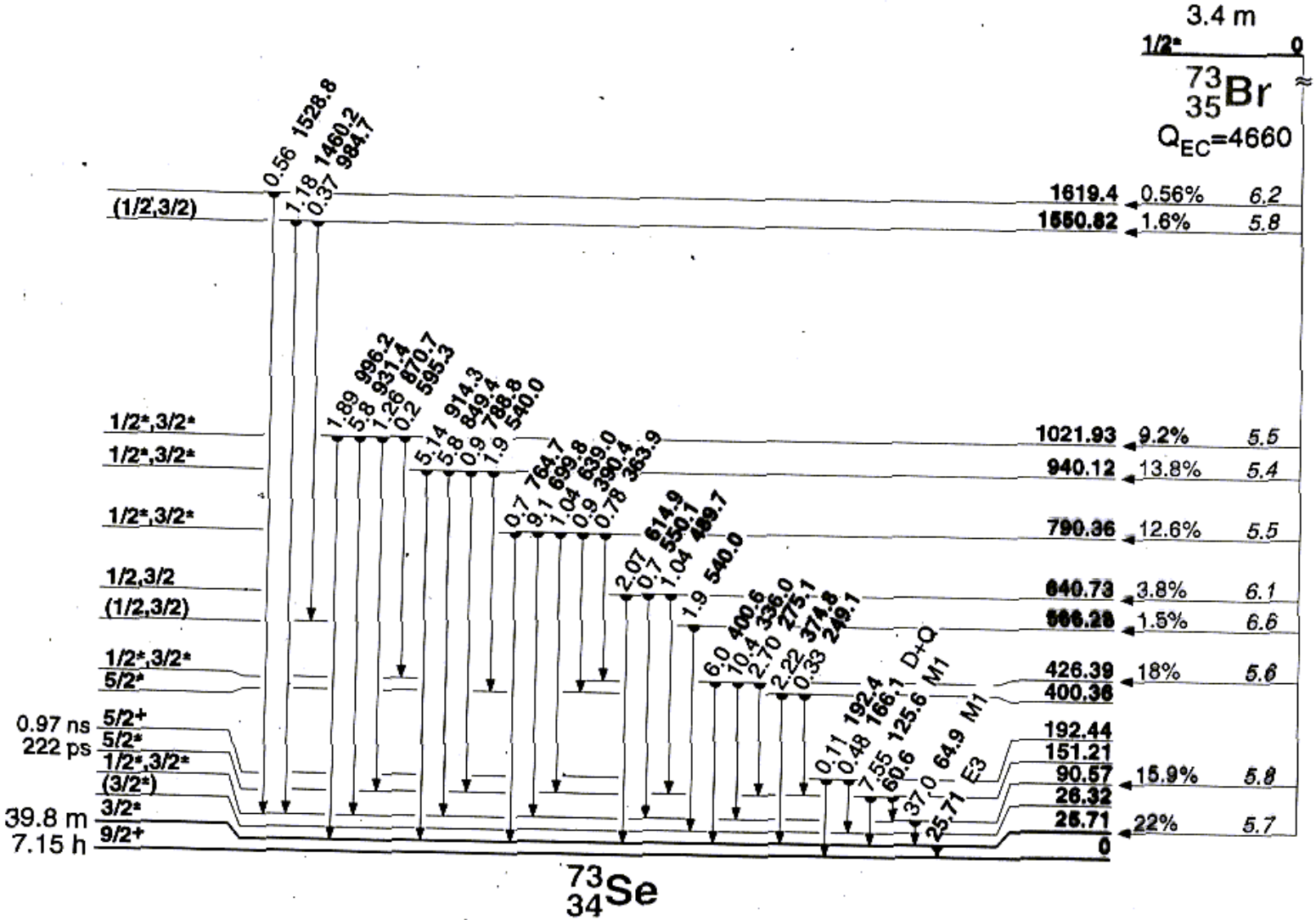
Nucleus	γ-ray Gate	β^+ Endpoint Energy	Q_{EC}
^{72}Br	454.70	5977 (394)	8316 (394)
	752.8	4771 (140)	8917 (140)
	1125.1	4633 (351)	8779 (351)
	1316.70	6171 (288)	8510 (288)
		(weighted mean)	8789 (113)

^{72}Br Mass Excess Values (keV)

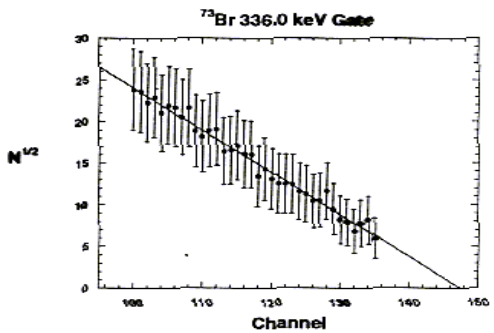
Our Work	-59105 (114)
Nubase[a]	-59150 (260)

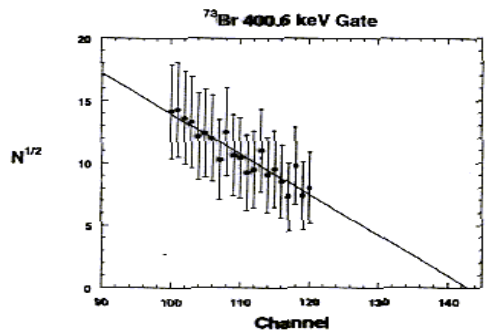
[a] G. Audi, O. Bersillon, J. Blachot, and A. H. Wapstra, Nucl. Phys. A624, 38 (1997). Values and uncertainties were estimated from systematic trends.

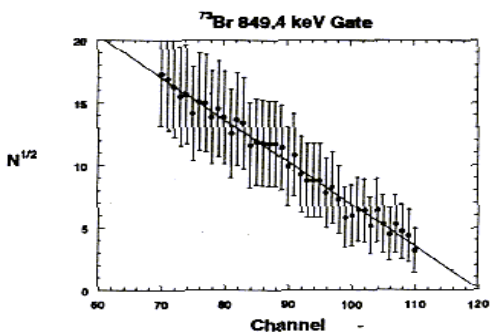
^{73}Br Decay Scheme

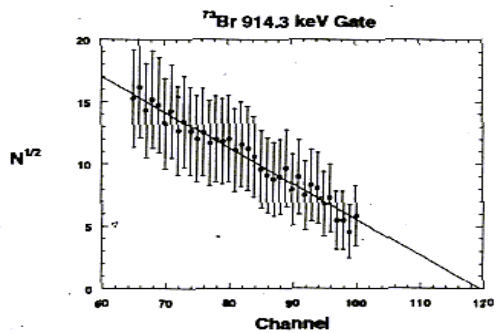


^{73}Br γ-ray Gated β^{+} Spectra

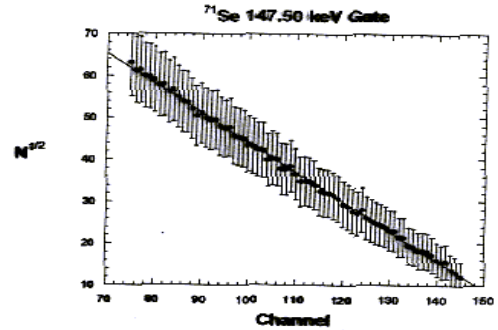


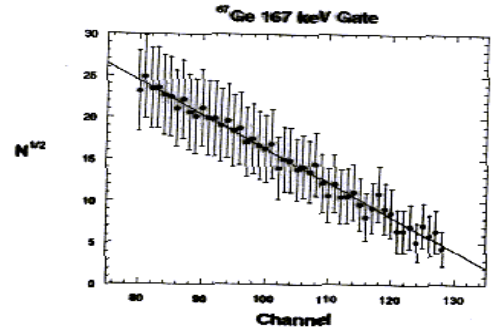


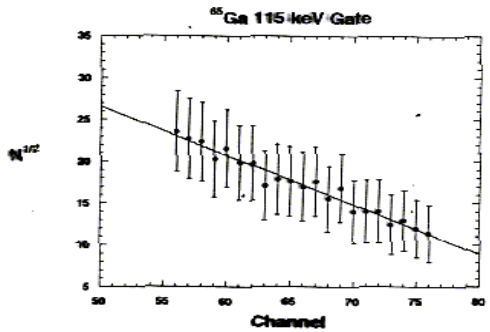


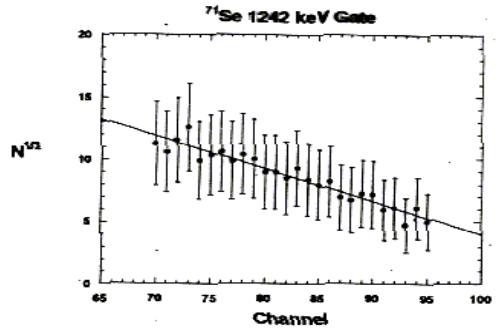


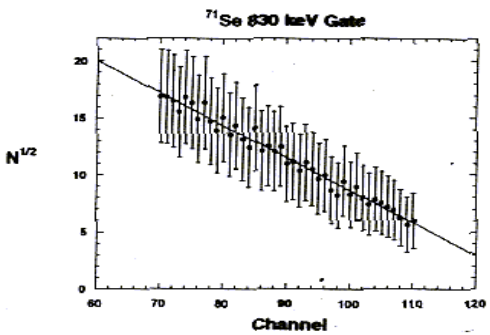
Calibrator Spectra

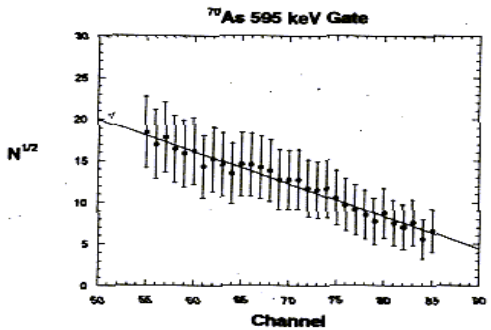




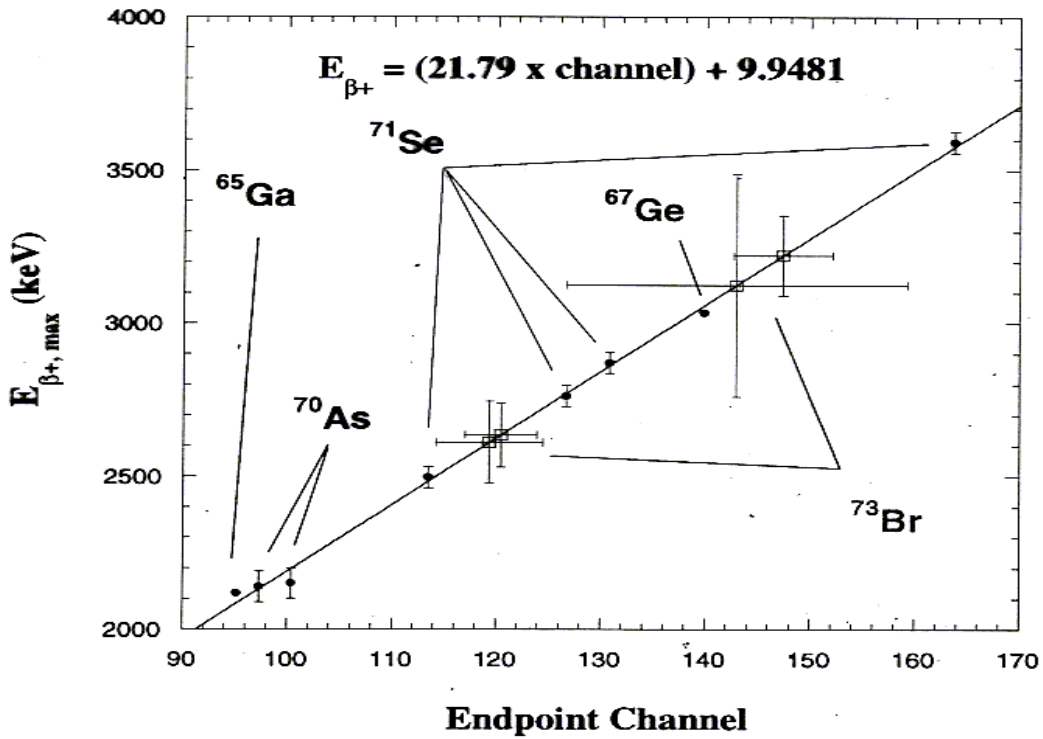








^{73}Br $E_{\beta+,\,max}$ Calibration Curve



β^+ Endpoint Energies and Q_{EC} Values (keV)

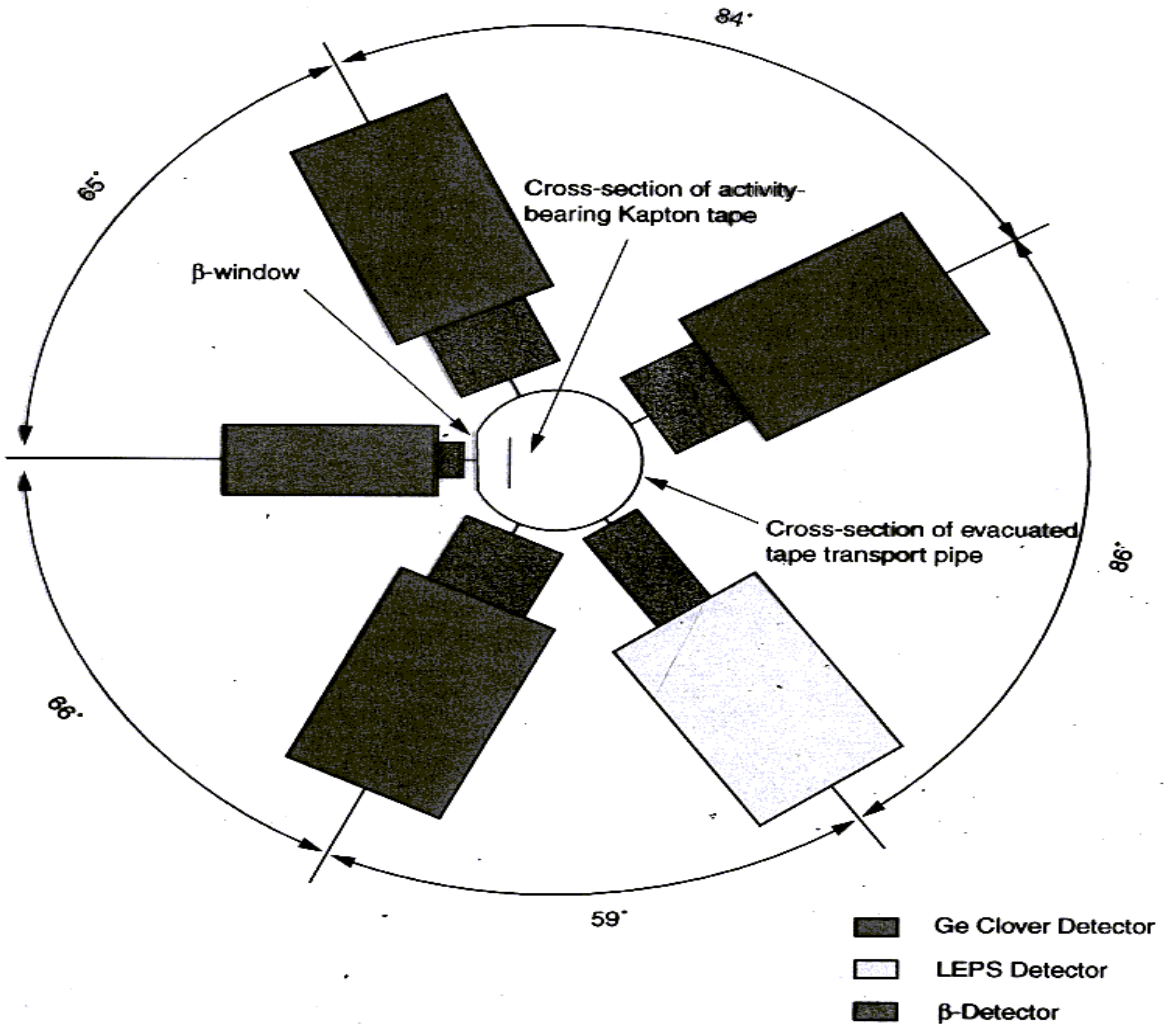
Nucleus	γ-ray Gate	β^+ Endpoint Energy	Q_{EC}
^{73}Br	336.0	3222 (131)	4670 (131)
	400.6	3125 (364)	4573 (364)
	914.3	2611 (134)	4573 (134)
	849.4	2635 (105)	4597 (105)
		(weighted mean)	4610 (69)

^{73}Br Mass Excess Values (keV)

Our Work	-63606 (70)
Nubase[a]	-63560 (130)

[a]G. Audi, O. Bersillon, J. Blachot, and A. H. Wapstra, Nucl. Phys. A624, 38 (1997). Values and uncertainties were estimated from systematic trends.

Detector Arrangement in ^{73}Br Experiment



Q_{EC} Values (MeV)

	^{70}Se	^{71}Se	^{72}Br	^{73}Br
Our work	2.736 (56)	4.762 (35)	8.869 (95)	4.610 (69)
Ref. (a)	2.5 (2)	——	——	——
Ref. (b)	——	4.428 (125)	——	——
Ref. (c)	——	——	——	4.66 (14)
Ref. (d)	——	——	——	4.7 (5)
Ref. (e)	——	——	——	4.6 (4)

(a) J. J. LaBreque, I. L. Preiss, H. Bakhru, and R. I. Morse, J. Inorg. Nucl. Chem. 37, 623 (1975).

(b) H. Schmeing, J. C. Hardy, R. L. Graham, J. S. Geiger, and K. P. Jackson, Phys. Lett 44B, 449 (1973).

(c) K. Heiguchi, S. Mitarai, B. J. Min, and T. Kuroyanagi, Nucl. Phys. A474, 484 (1987).

(d) G. Murray, W. J. K. White, and J. C. Willmott, Nucl. Phys. A142, 21 (1970).

(e) E. Roeckl, D. Lode, K. Bächman, B. Niedhart, G. K. Wolf, W. Lauppe, N. Kaffrell, and P. Patzelt, Z. Phys. 266, 65 (1974).

Mass Excess Values (MeV)

	^{70}Se	^{71}Se	^{72}Br	^{73}Br
Our work	-61.604 (75)	-63.130 (35)	-59.025 (96)	-63.606 (70)
Nubase (a)	-61.940 (210)	-63.090 (200)	-59.150 (260)	-63.530 (130)
Ref. (b)	-62.31 (46)	-63.49 (32)	-----	-----
Ref. (c)	-----	-----	-59.215 (294)	-----
MNMS (d)	-61.87	-63.39	-59.45	-63.81
APDT (e)	-60.2	-62.3	-58.2	-63.3
NS (f)	-61.74	-63.50	-59.11	-63.78

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Conclusions

- *precision mass measurements can be made in the vicinity of the rp process line by using the classic method of β-γ coincidence spectroscopy if appropriate target/projectile combinations are available*

- *the use of modern, high-efficiency γ-ray detectors has improved the sensitivity and selectivity of the method*

- *experiments should be feasible for nuclides with half-lives $\geq$1 s which are produced with cross sections of $\geq$25 mb*

- *such measurements are important to calculations of the rp process path and to predictions of solar abundances for neutron-deficient nuclides*

Plans for Experiments at Yale

- *candidates for future mass measurements are ^{80}Y and other nuclei in the rp-process region*