NEUTRON-INDUCED FISSION PRODUCT STUDIES AT 0.17 s TO 50,000 s AFTER FISSION

--- A REVIEW OF PAST PRACTICES ---

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Fission Nuclides

- ^{235}U (thermal neutrons, fast neutrons)
- ^{238}U (fast neutrons)
- ^{239}Pu (thermal neutrons)

Types of Studies and Purpose

- Provide nuclear data to ENDF/B-VI for fast breeder reactor design calculations
- Delayed neutron energy spectra (0.17 s to 85 s)–Control of fast breeder reactor
- Beta and gamma decay heat studies (0.3 s to 50,000 s)–Loss of coolant accident
- Cumulative and independent yields of fission products (0.2 s to 10,000 s)

  (e.g.only 25% of ^{235}U fission product yields were measured in 1992)

Sources of Neutrons

- $^{7}Li(p,n)^{7}Be$ on thick target at 5.5 MV Van de Graaff (moderated or fast neutrons)
- Thermal neutron column or fast neutron port at 1 MW research reactor

The Challenge

- Intense production of fission fragments
- Rapid and uniform transfer of fission fragments from intense neutron environment to low-background counting room.

Helium Jet and Tape Transport System

Hemispherical fission chamber

- 17 mm radius and lined with fission foils
- Uniform fission fragment stopping in gas at 3 atmospheres helium

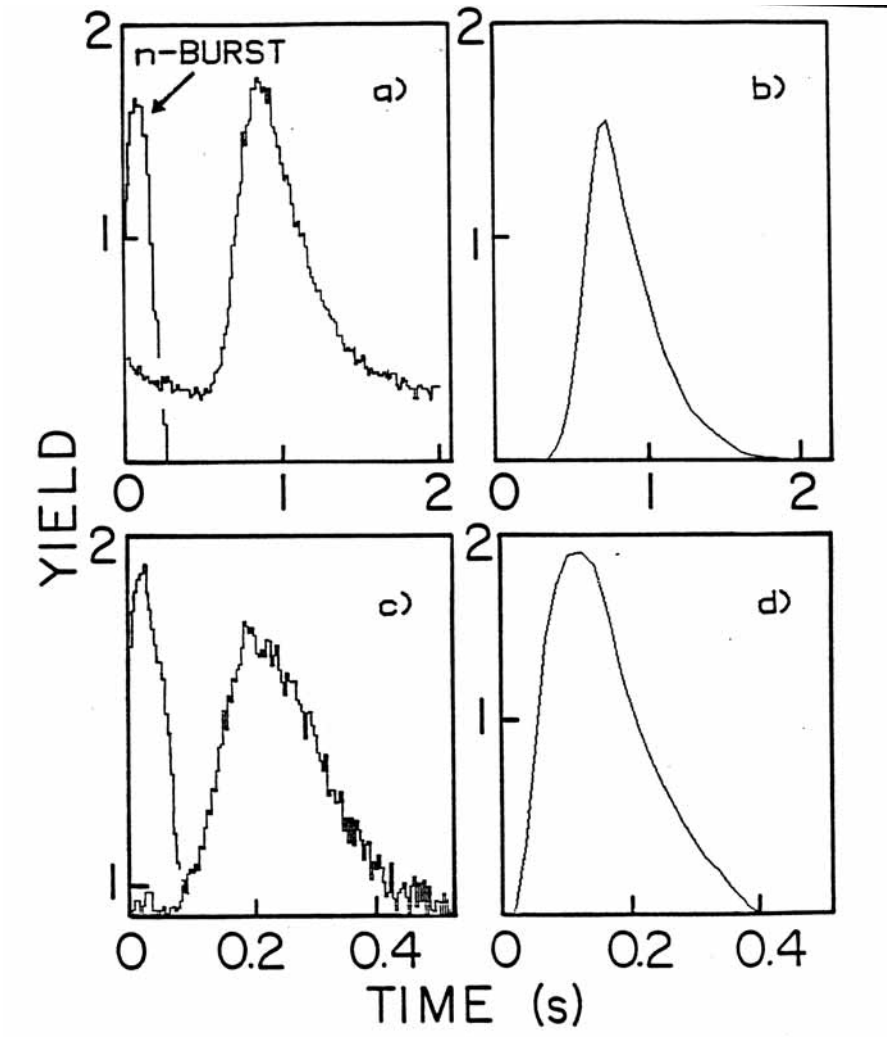
Helium jet system

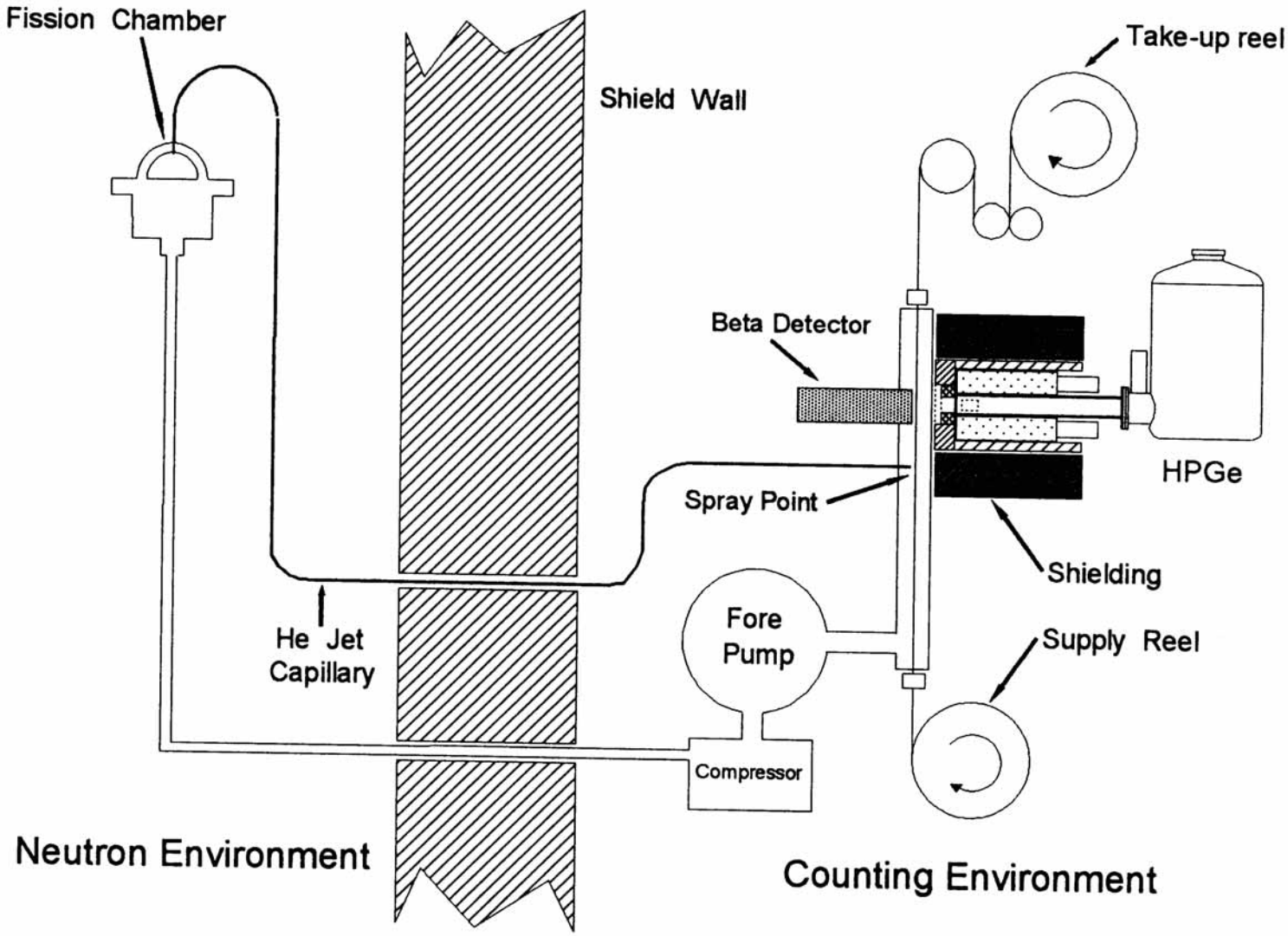
- Helium mechanically saturated with fore pump oil vapor
- Uniform transfer of fission products verified in characteristic x-ray study

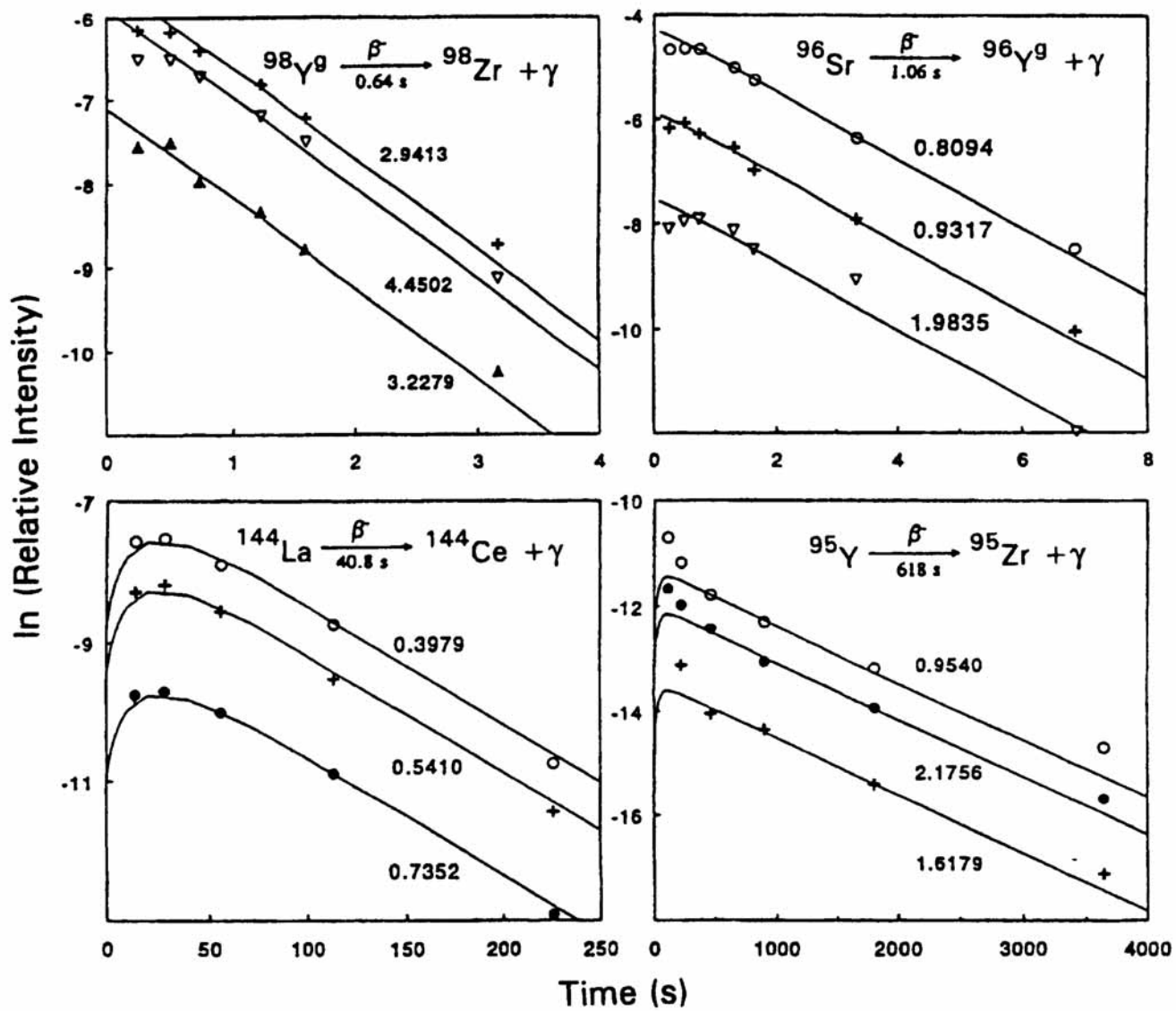
Tape transport system

- Chose continuous, adjustable tape speed (from very rapid to very slow)
- Uniform sensitivity throughout the dwell-time interval at the detector

Fission Chamber "Flush" Time + He-Jet Transfer Time

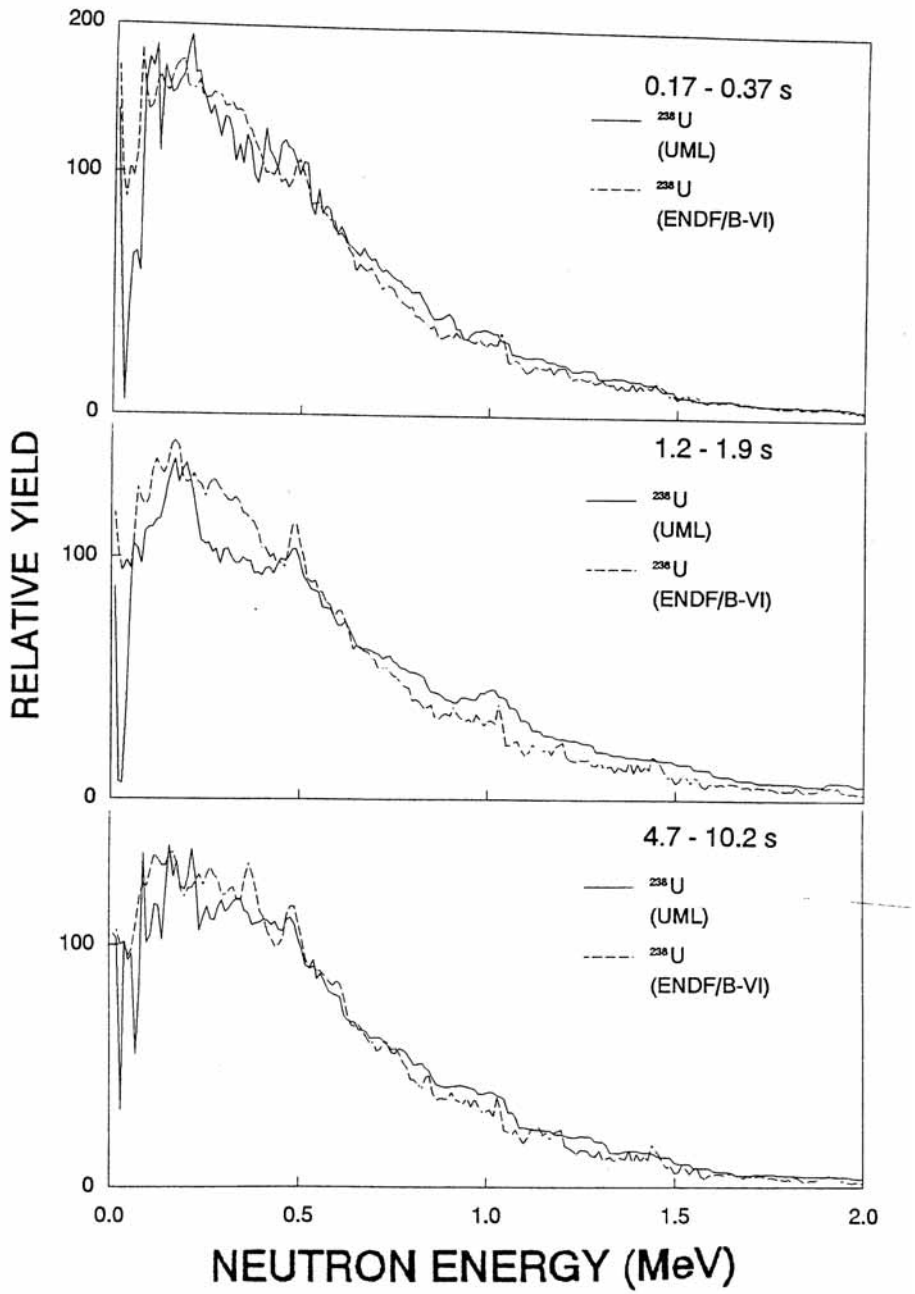


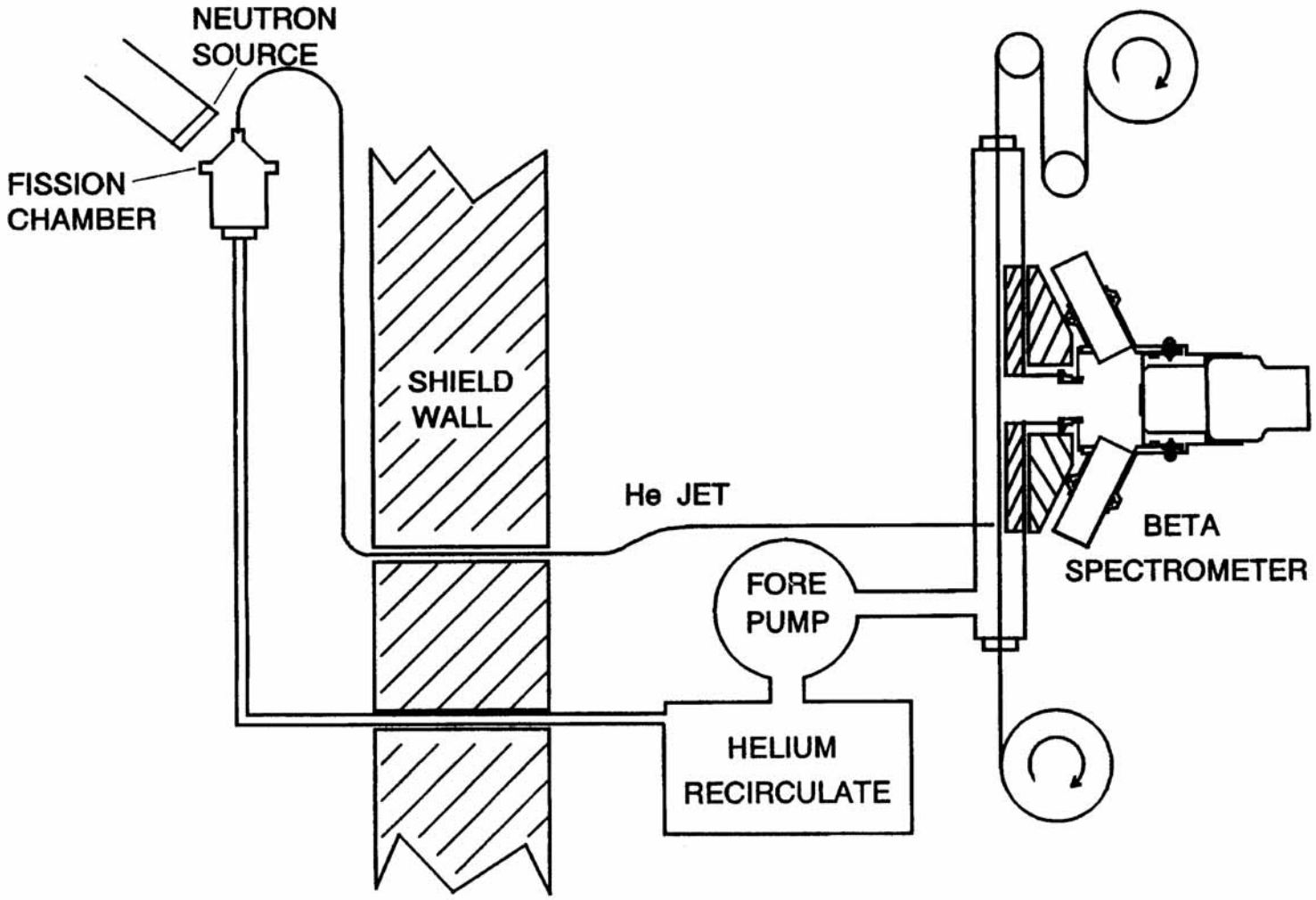

Fission Chamber
Shield Wall
Take-up reel
Beta Detector
HPGe
Spray Point
Shielding
He Jet
Capillary
Fore
Pump
Supply Reel
Compressor
Neutron Environment
Counting Environment


ln (Relative Intensity)
Time (s)
98Yg β- 0.64 s 98Zr +γ
2.9413
4.4502
3.2279
96Sr β- 1.06 s 96Yg +γ
0.8094
0.9317
1.9835
144La β- 40.8 s 144Ce +γ
0.3979
0.5410
0.7352
95Y β- 618 s 95Zr +γ
0.9540
2.1756
1.6179

Comparison of Independent Fission Fragment Yields for ^{235}U Fission

Isotope	$t_{1/2}$	ENDF	Expt.	Rudstam	Expt./ENDF	Expt./Rudstam
^{89}Rb	15.2 m	0.20 (11)	0.91 (14)	1.17 (9)	4.6 (18)	0.78 (17)
$^{90}Rb^{g}$	2.55 m	0.139 (6)	0.61 (15)	0.43 (16)	4.3 (16)	1.42 (22)
$^{90}Rb^{m}$	4.3 m	0.71 (>64)	1.6 (12)	0.59 (12)	2.2 (>65)	2.7 (17)
^{91}Rb	58.4 s	2.225 (1.4)	2.9 (13)	2.24 (2)	1.30 (13)	1.29 (13)
$^{92}Rb^{c}$	4.5 s	3.132 (2)	5.7 (38)	2.75 (11)	1.8 (38)	2.1 (40)
^{93}Rb	5.7 s	3.067 (1.4)	3.3 (13)	2.95 (8)	1.08 (13)	1.12 (15)
^{93}Sr	7.42 m	2.570 (2)	2.1 (35)	1.98 (21)	0.8 (35)	1.1 (41)
^{94}Rb	2.7 s	1.567 (3)	1.17 (11)	1.24 (9)	0.75 (12)	0.94 (14)
^{94}Sr	1.25 m	4.513 (1.4)	4.6 (14)	4.7 (15)	1.02 (14)	0.98 (21)
^{95}Rb	0.38 s	0.764 (4)	0.69 (13)	0.71 (7)	0.90 (14)	0.97 (15)
^{95}Sr	25.1 s	4.538 (2)	5.3 (14)	4.51 (2)	1.17 (14)	1.18 (14)
^{96}Sr	1.06 s	3.568 (2)	2.5 (13)	3.63 (2)	0.70 (13)	0.69 (13)
$^{96}Y^{m}$	9.6 s	2.02 (32)	0.94 (11)		0.47 (34)	
^{97}Sr	0.42 s	1.721 (3)	0.81 (14)	2.58 (21)	0.47 (14)	0.31 (25)
$^{97}Y^{g}$	3.5 s	3.14 (32)	1.4 (25)		1.1[a] (34)	
$^{97}Y^{m}$	1.23 s		2.0 (13)			
$^{98}Y^{g}$	0.64 s	1.11 (32)	1.4 (13)		1.3 (35)	
$^{98}Y^{m}$	2.0 s	1.11 (32)	0.8[b] (43)		0.7 (54)	
^{99}Y	1.47 s	1.950 (6)	1.2 (19)		0.62 (20)	
^{99}Zr	2.1 s	3.58 (23)	3.3 (28)		0.92 (36)	
$^{99}Nb^{m}$	2.6 m	0.407 (8)	5.0 (19)		12.3 (21)	
$^{100}Y^{g}$	0.74 s	0.61 (>64)	0.24 (22)		0.39 (>68)	
^{100}Zr	7.1 s	4.98 (32)	4.1 (16)		0.82 (36)	
^{101}Zr	2.1 s	2.788 (4)	2.8 (12)		1.01 (13)	
^{102}Zr	2.9 s	1.782 (4)	3.9 (12)		2.19 (13)	
$^{136}I^{g}$	1.39 m	1.320 (8)	1.2 (29)	0.29 (83)	0.91 (30)	4.1 (88)
$^{136}I^{m}$	46.9 s	1.251 (6)	1.07 (15)	1.09 (11)	0.86 (16)	0.98 (19)
^{140}Cs	1.06 m	2.070 (3)	2.6 (13)	2.4 (25)	1.26 (13)	1.1 (28)
^{141}Cs	24.9 s	2.915 (2)	4.3 (13)	3.11 (3)	1.48 (13)	1.38 (13)
^{141}Ba	18.27 m	1.66 (11)	1.7 (57)		1.0 (58)	
^{142}Cs	1.7 s	2.278 (4)	2.2 (15)	2.23 (17)	0.97 (16)	0.99 (23)
^{142}Ba	10.6 m	3.014 (6)	3.7 (21)		1.23 (22)	
^{143}Cs	1.78 s	1.403 (4)	1.3 (19)		0.93 (20)	
^{143}Ba	14.5 s	4.101 (4)	3.4 (24)	6.1 (13)	0.83 (24)	0.56 (27)
^{143}La	14.1 m	0.38 (>64)	2.9 (51)		7.6 (>82)	
^{144}Ba	11.4 s	3.975 (3)	4.0 (16)	3.93 (1)	1.01 (16)	1.02 (16)
^{144}La	40.9 s	1.070 (6)	0.4 (325)		0.4 (325)	
^{145}Ba	4.31 s	1.866 (6)	1.8 (17)	2.25 (25)	0.96 (18)	0.80 (30)
^{145}La	24.8 s	1.915 (8)	3.8 (35)		2.0 (36)	
^{146}La	6.27 s	1.490 (8)	1.3 (25)		0.87 (26)	
^{147}La	4.4 s	0.64 (11)	1.6 (20)		2.5 (23)	


200
100
0
0.17 - 0.37 s
238U
(UML)
238U
(ENDF/B-VI)
1.2 - 1.9 s
238U
(UML)
238U
(ENDF/B-VI)
4.7 - 10.2 s
238U
(UML)
238U
(ENDF/B-VI)
RELATIVE YIELD
0.0
0.5
1.0
1.5
2.0
NEUTRON ENERGY (MeV)

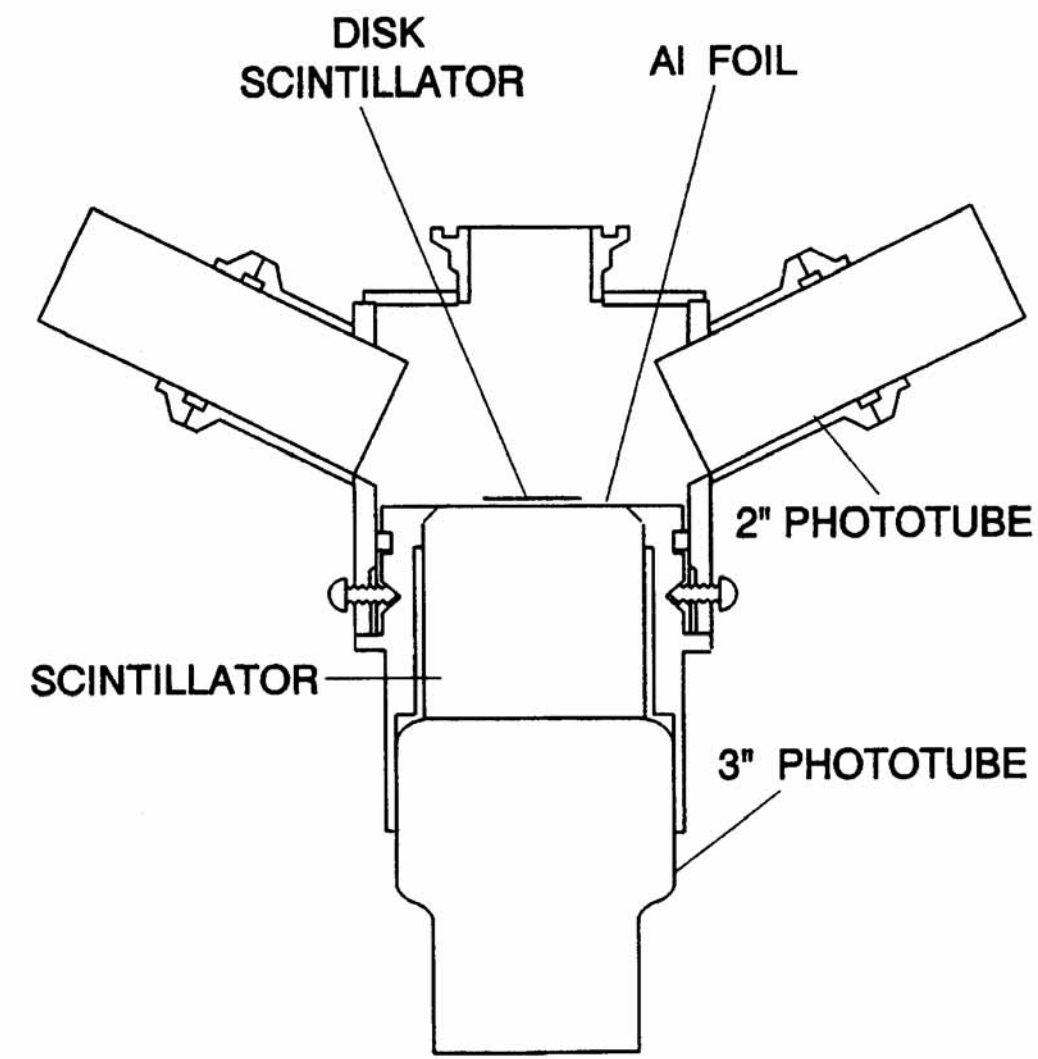

NEUTRON
SOURCE
FISSION
CHAMBER
SHIELD
WALL
He JET
FORE
PUMP
HELIUM
RECIRCULATE
BETA
SPECTROMETER

Beta decay heat measurements for ^{235}U, ^{238}U, ^{239}Pu 0.37s to 50,000s after neutron fission

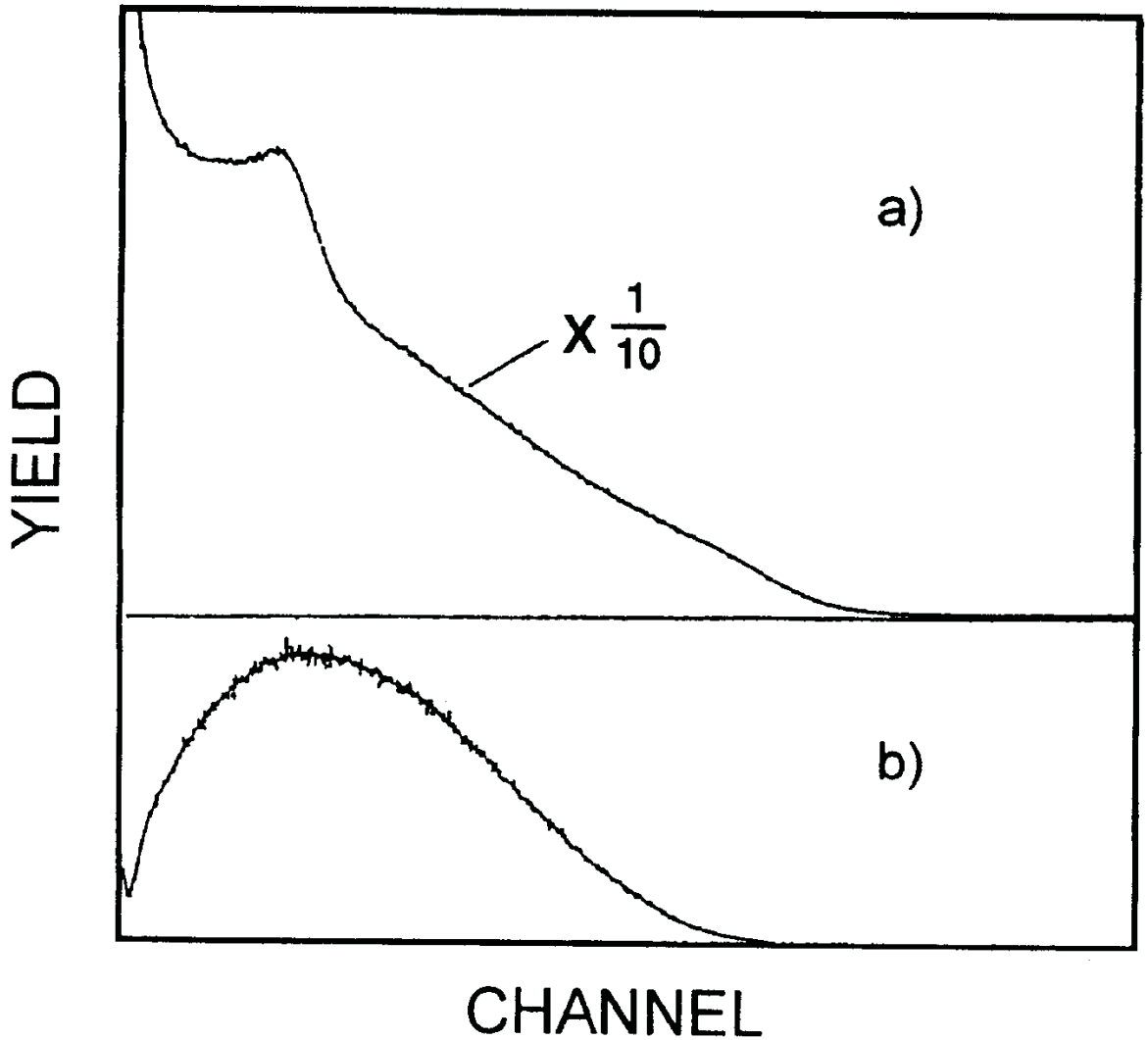
Beta spectrometer

- Gamma rejection
- Minimize edge effects
- Background subtraction
- Energy calibration
- Response functions
- Normalization
- Results with comparison to ENDF and previous measurements

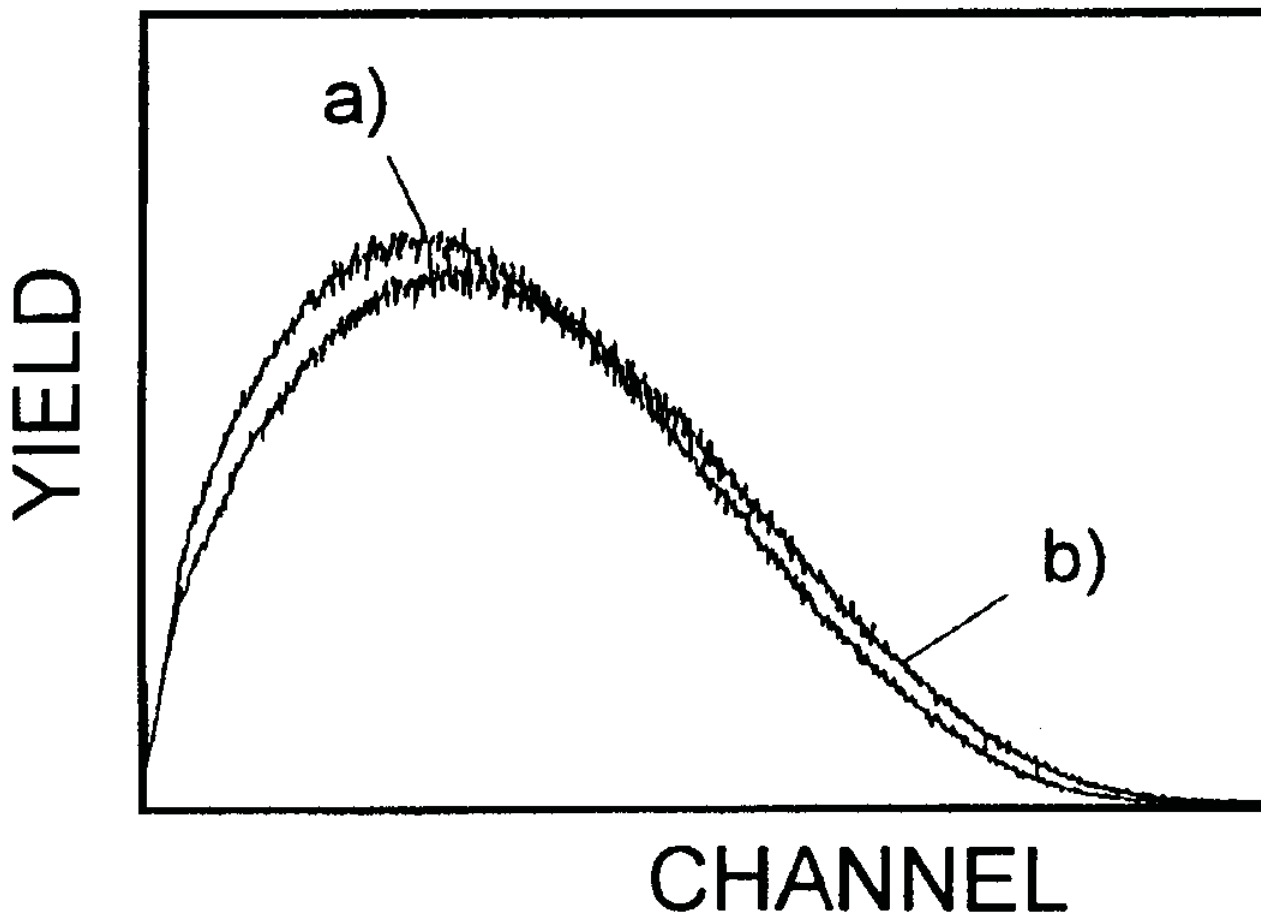
Beta Decay Heat Spectrometer



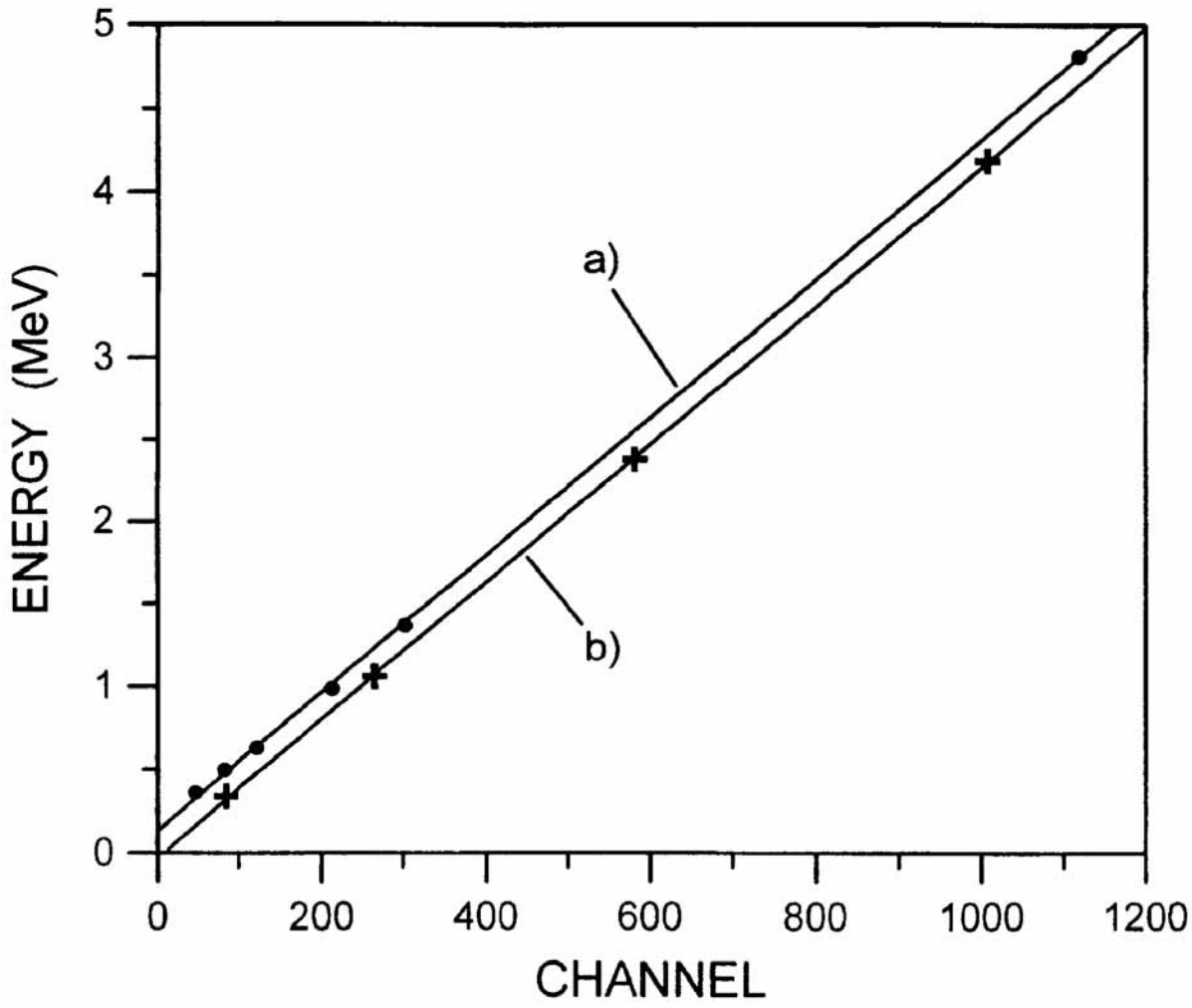
Gamma ray rejection



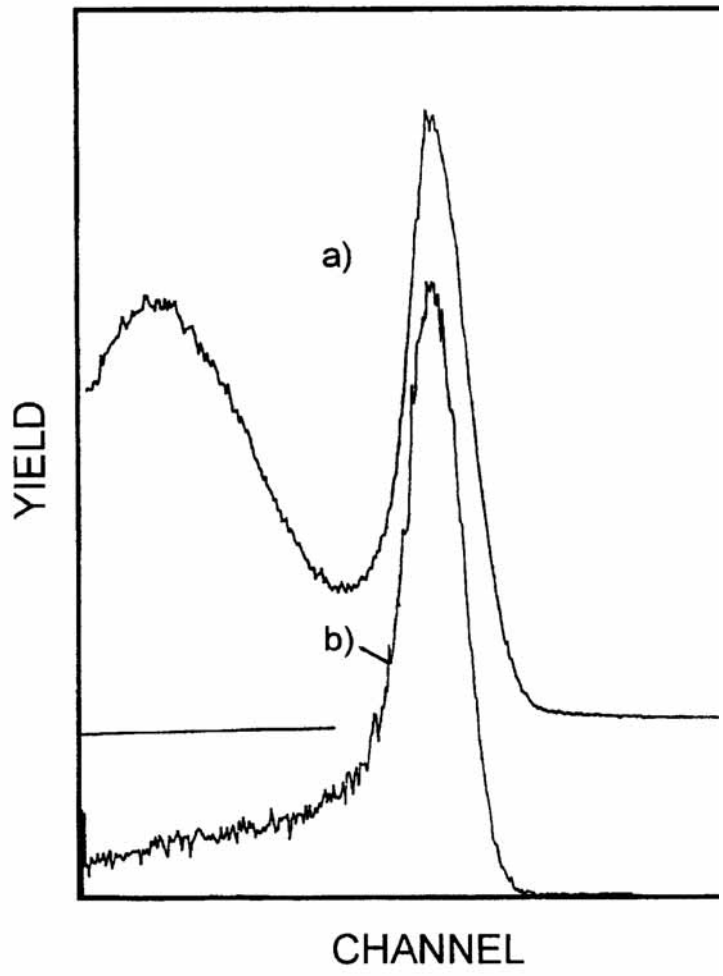
Edge effects



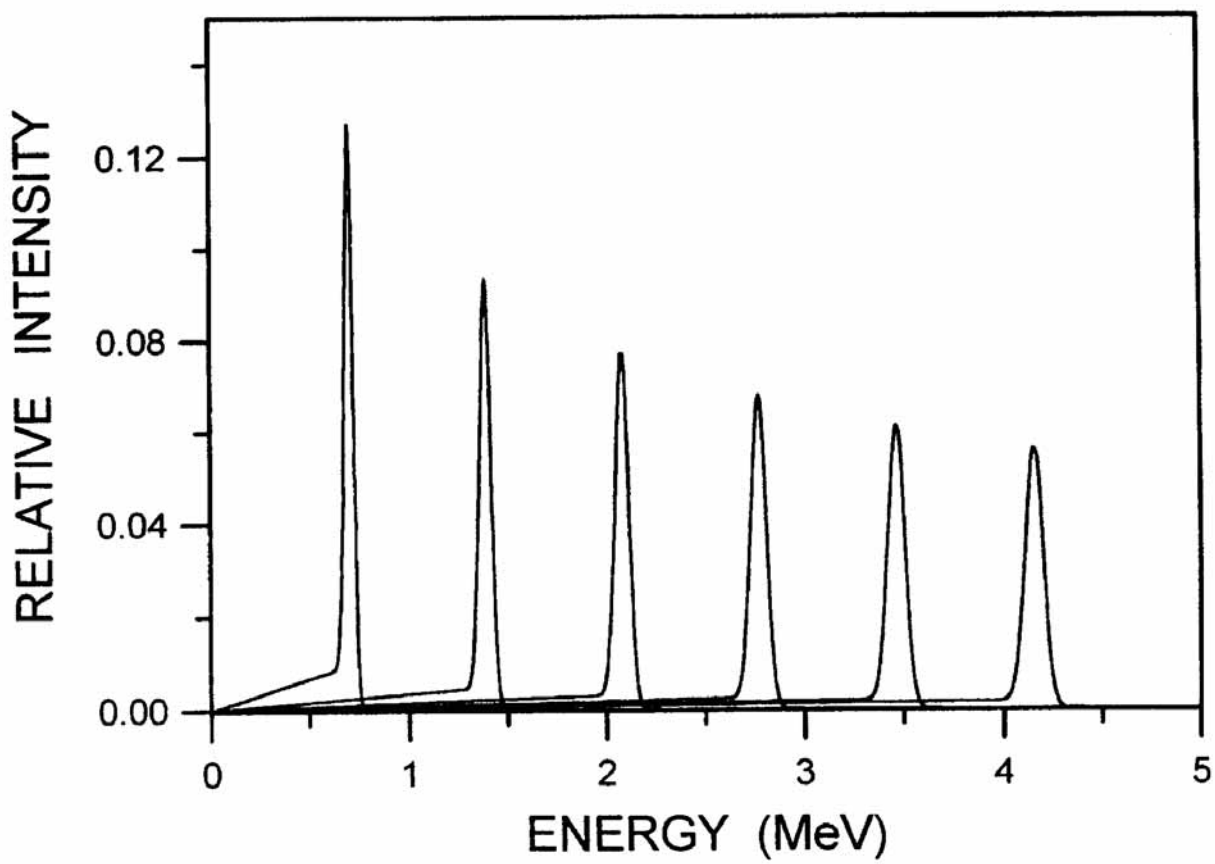
Energy Calibration



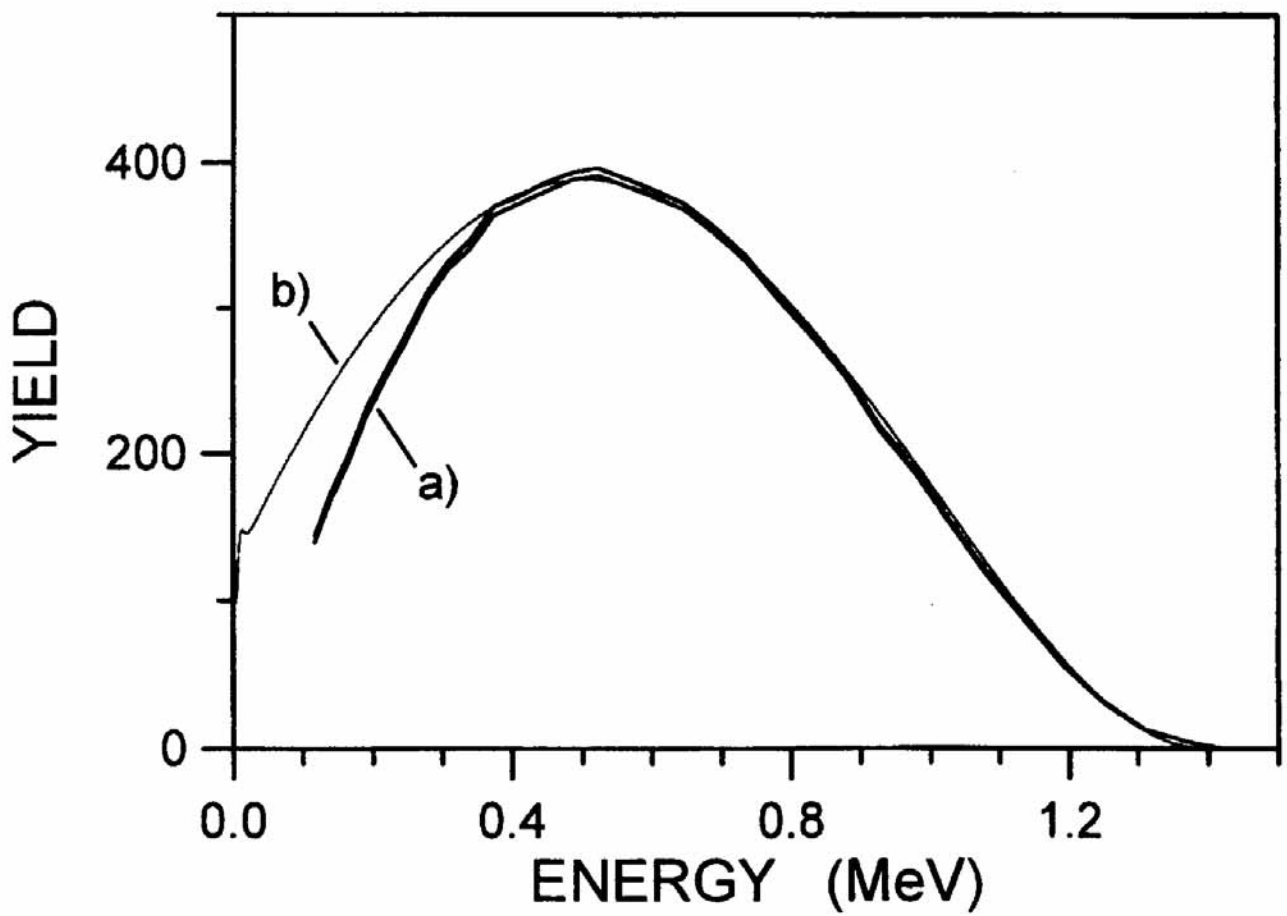
^{137}Cs (IT) Response Function



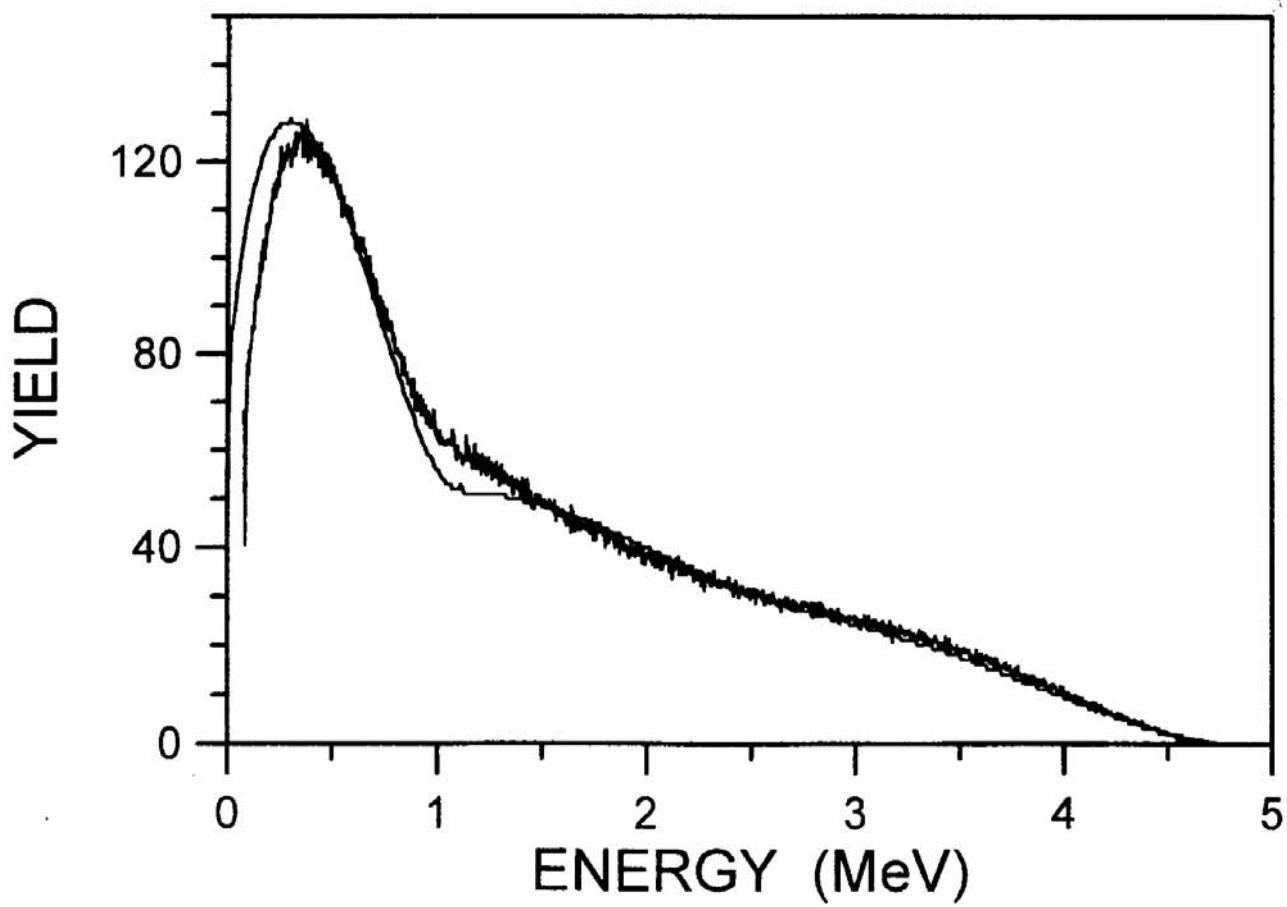
Response function set



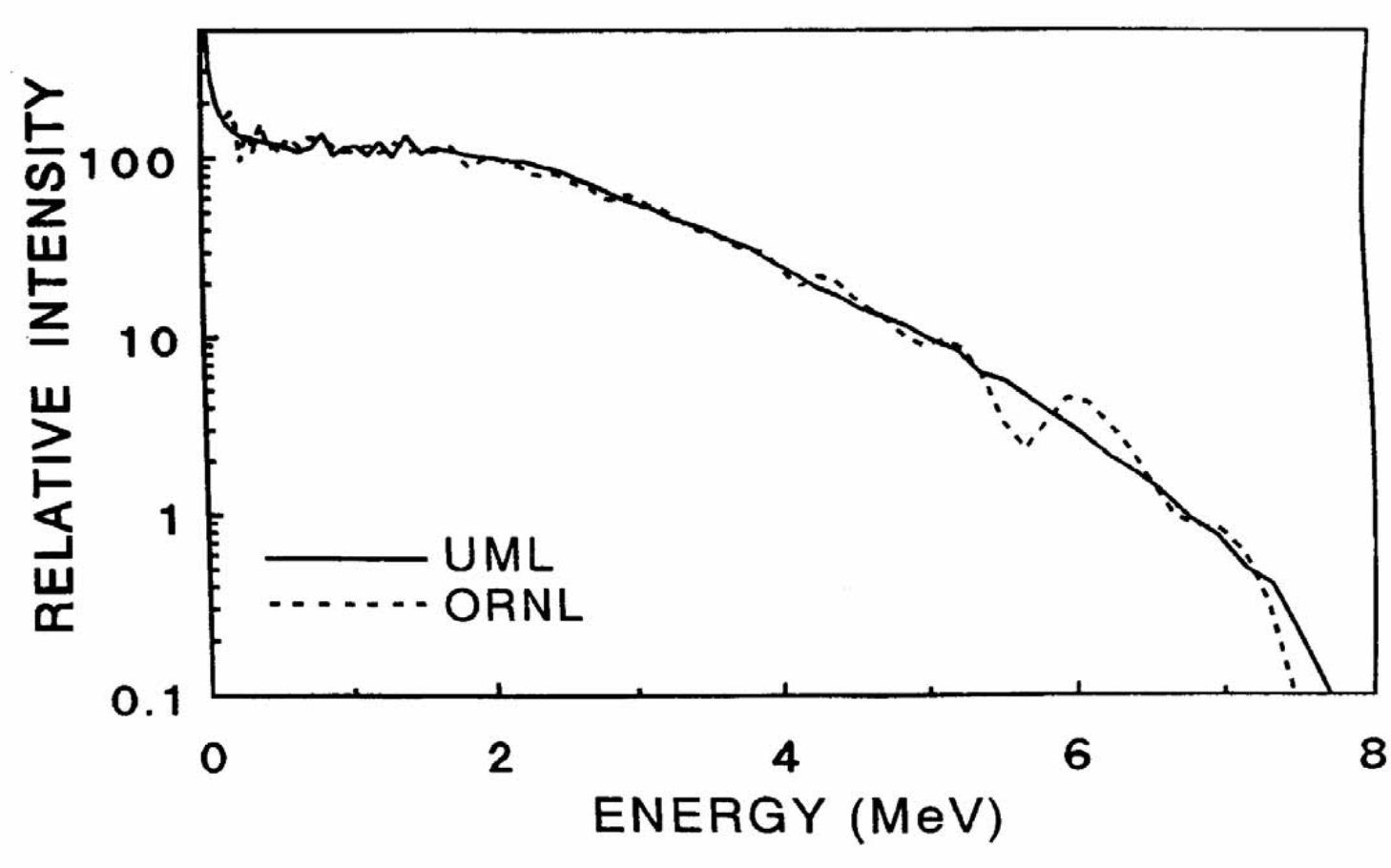
^{24}Na beta spectrum



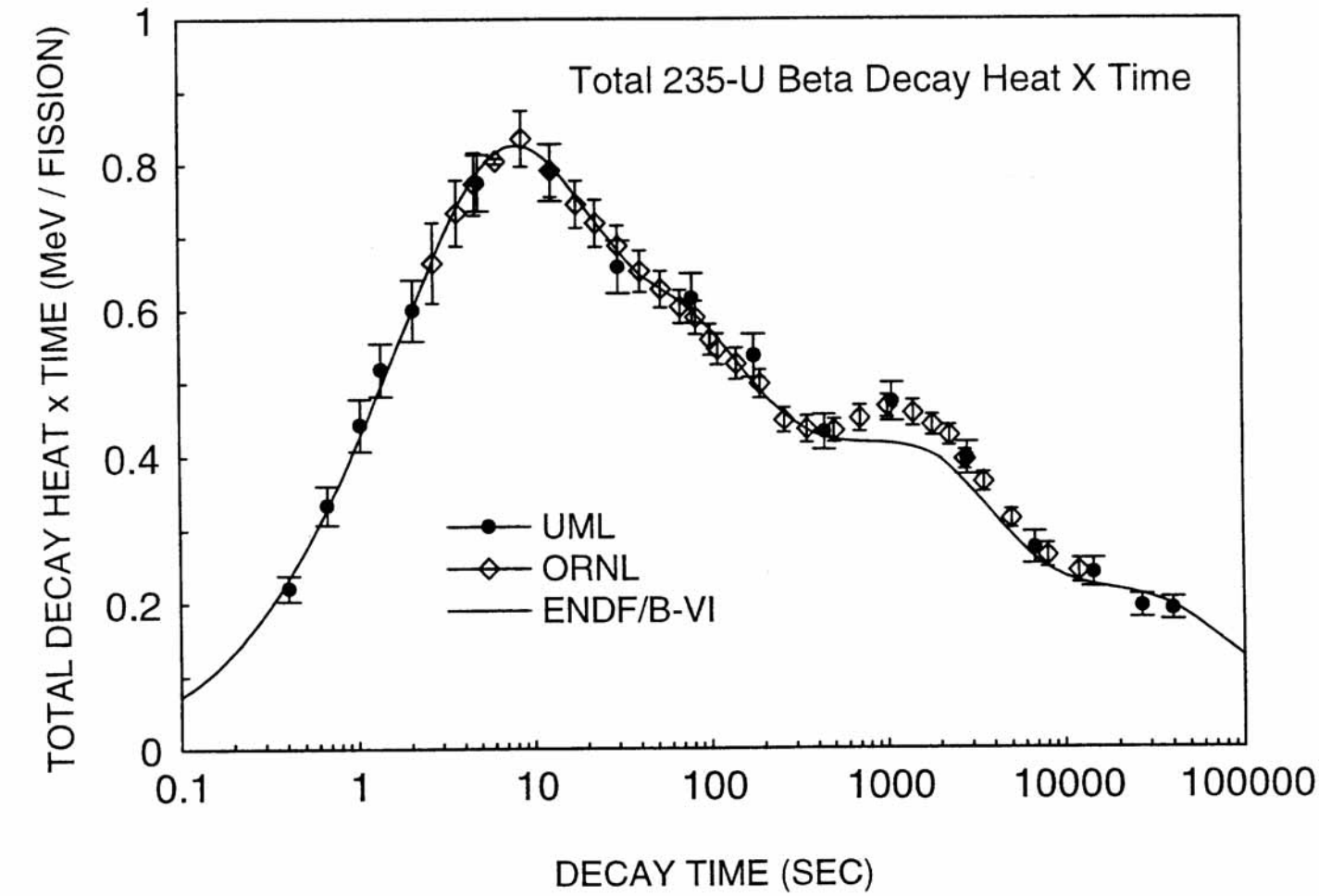
^{38}Cl beta spectrum (three beta spectra)



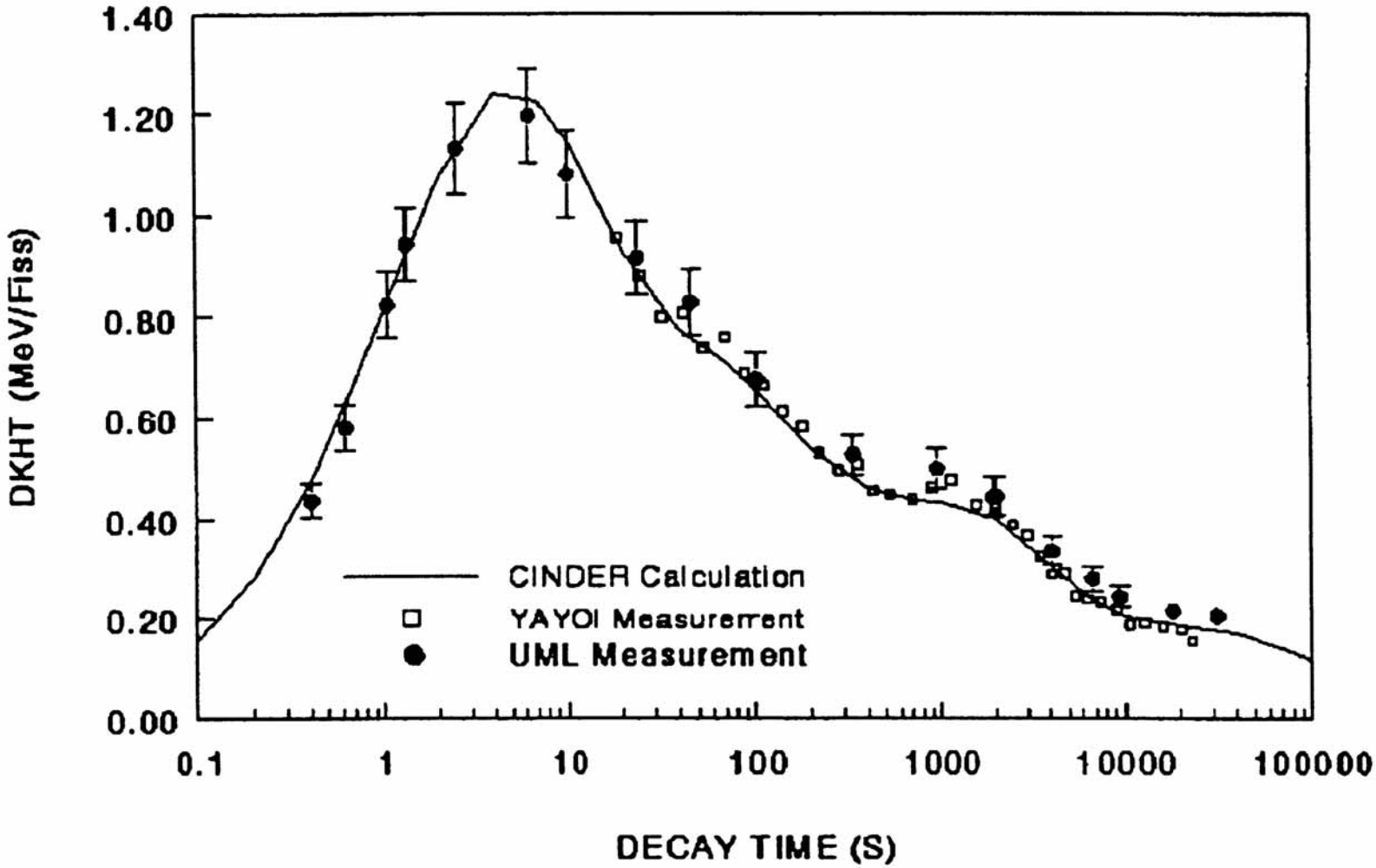
Beta decay heat energy spectrum from neutron fission of ^{235}U



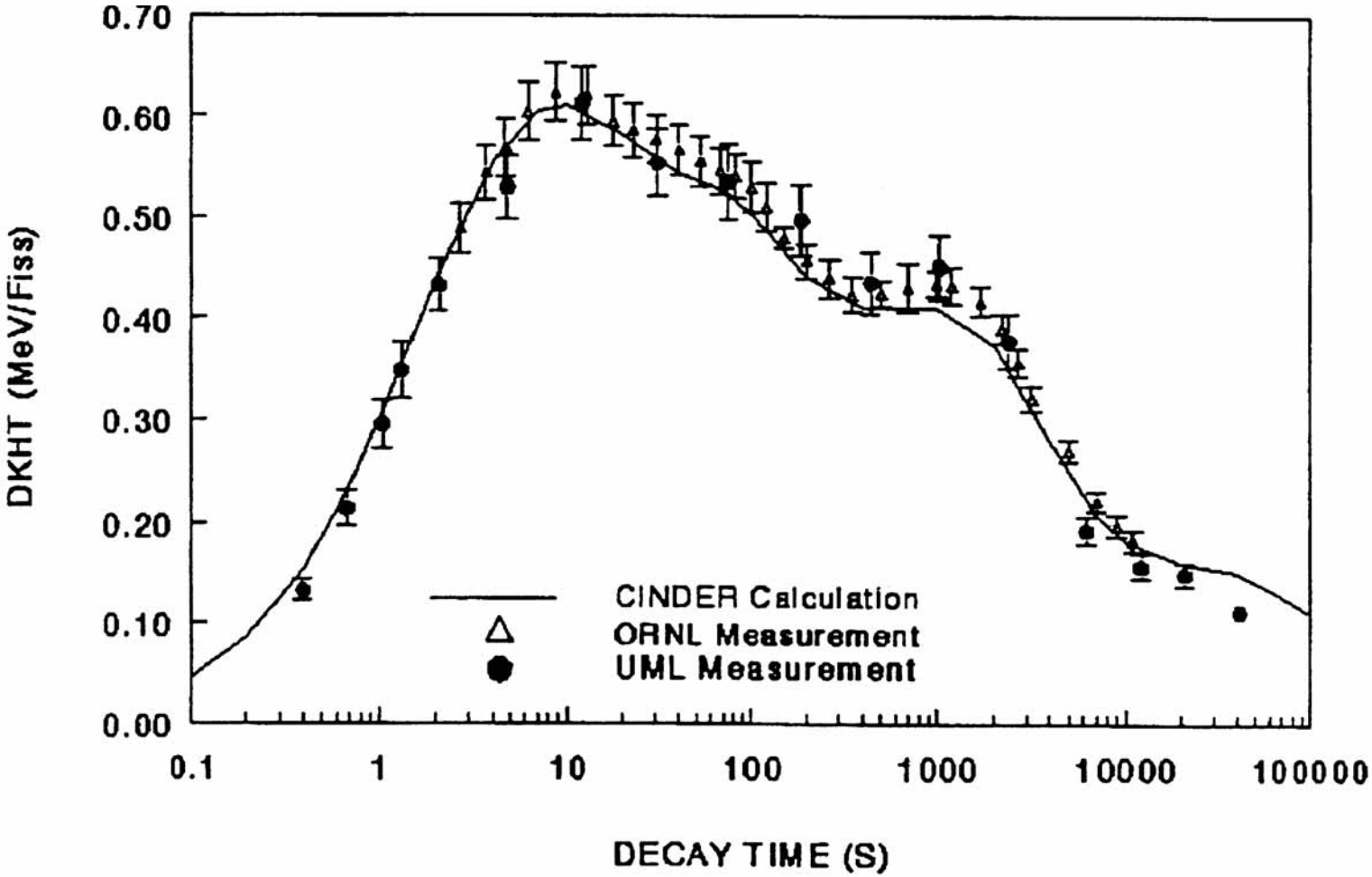
Beta Decay Heat from ^{235}U Fission



Beta Decay Heat from ^{238}U Fission



Beta Decay Heat from ^{239}Pu Fission

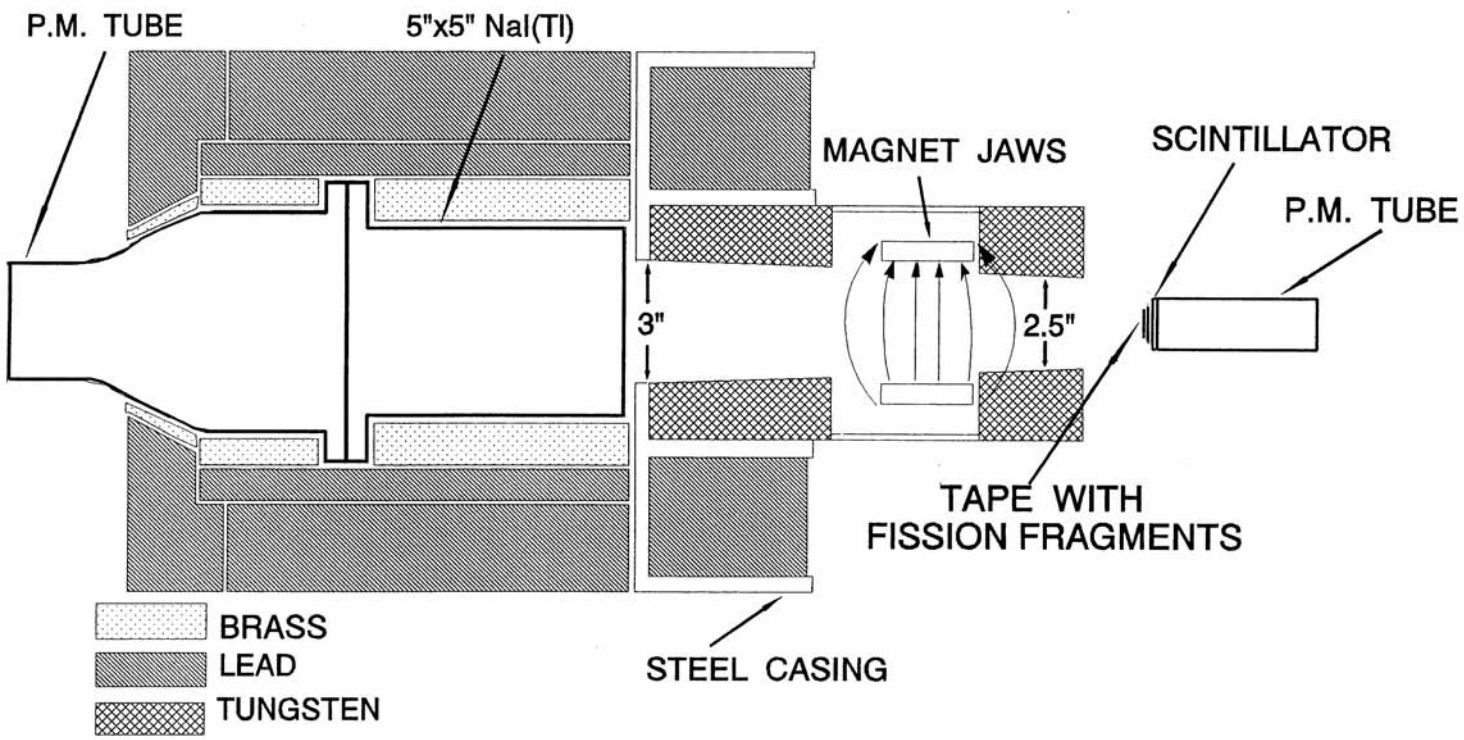


Gamma decay heat measurements for ^{235}U, ^{238}U, ^{239}Pu 0.37 s to 50,000 s after neutron fission

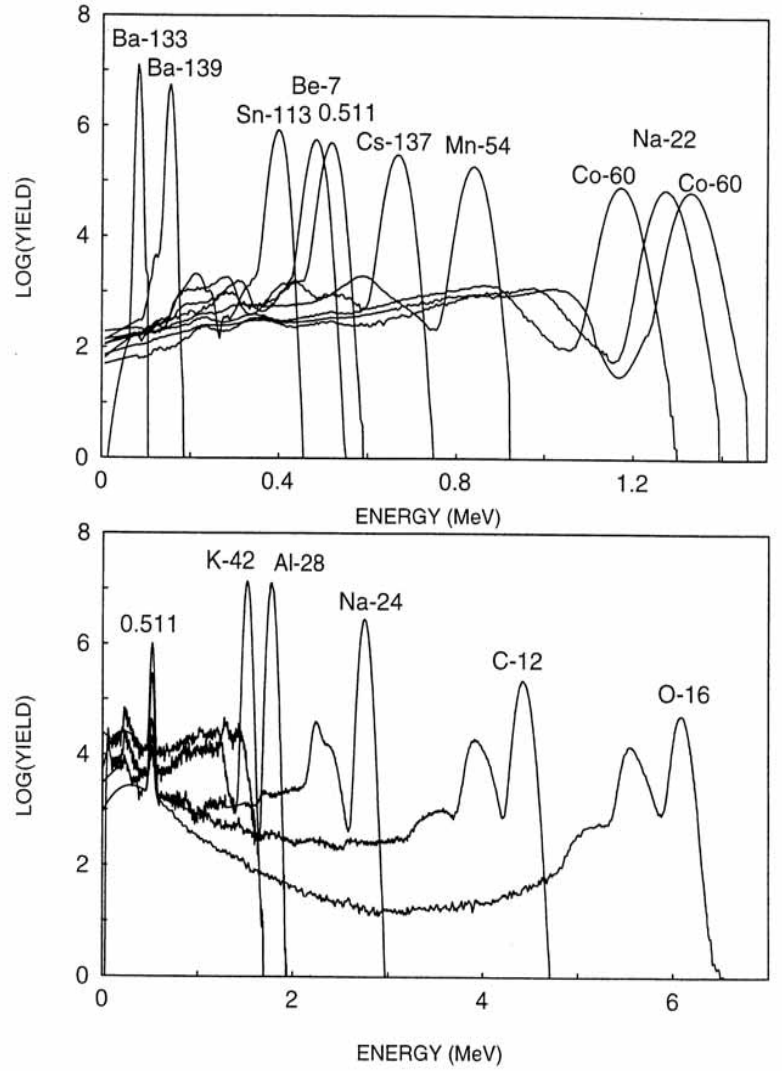
Gamma-ray Spectrometer

- Beta rejection
- Minimize edge effects
- Background subtraction
- Energy calibration
- Response function
- Normalization
- Results with comparison to ENDF and previous measurements

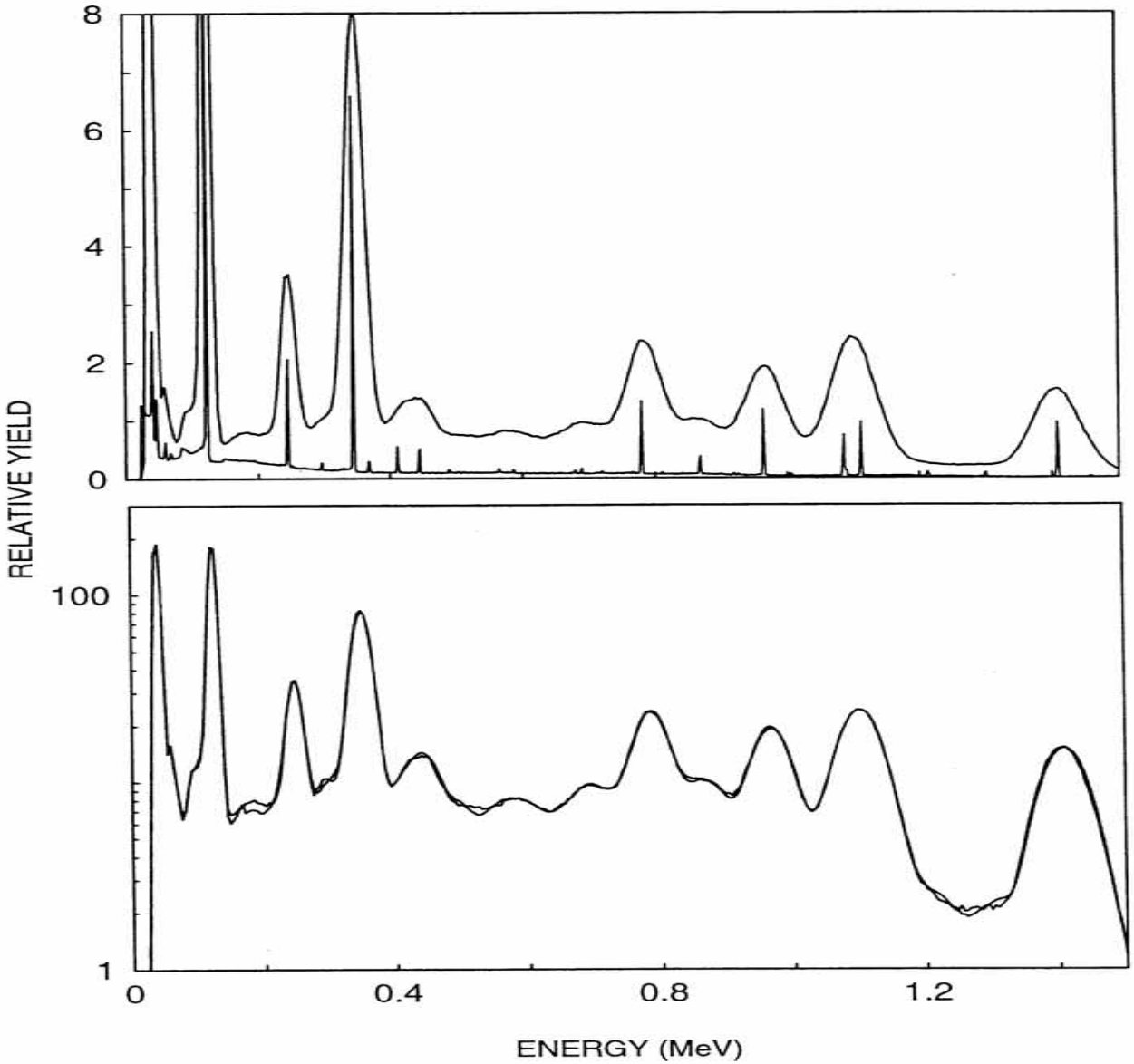
Gamma-ray Decay Heat Spectrometer



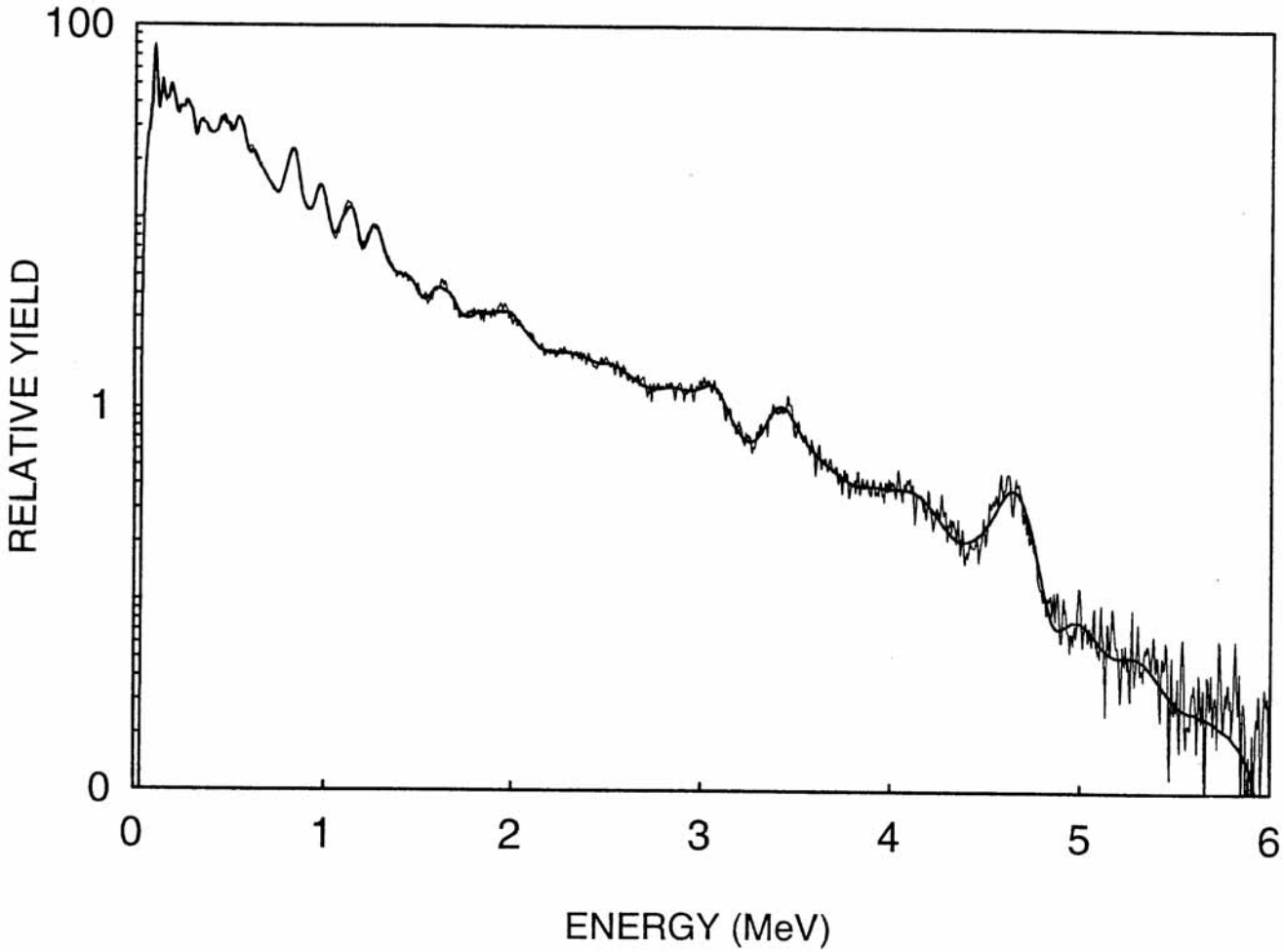
Response Functions



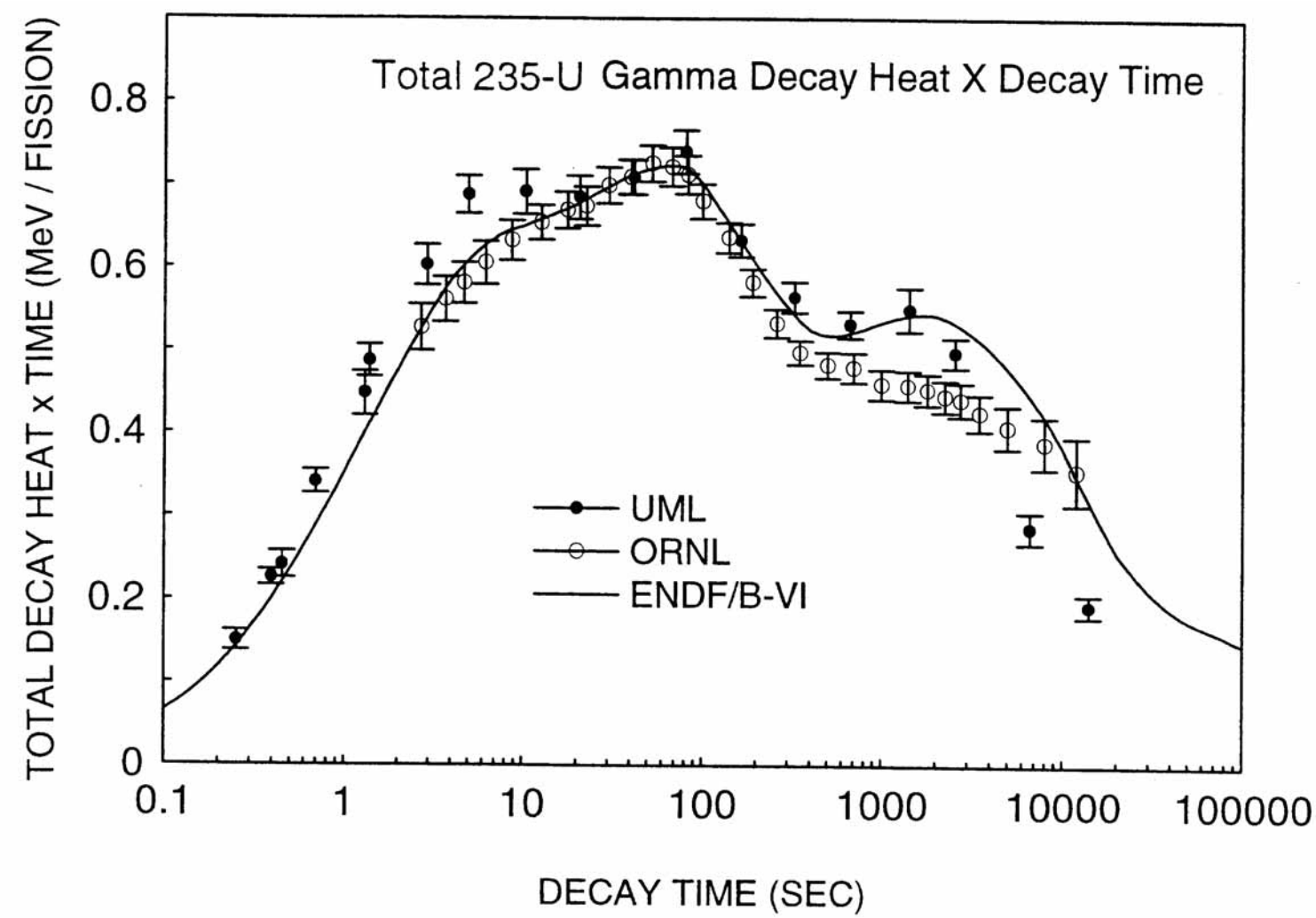
Response Function Fit of ^{152}Eu Gamma rays



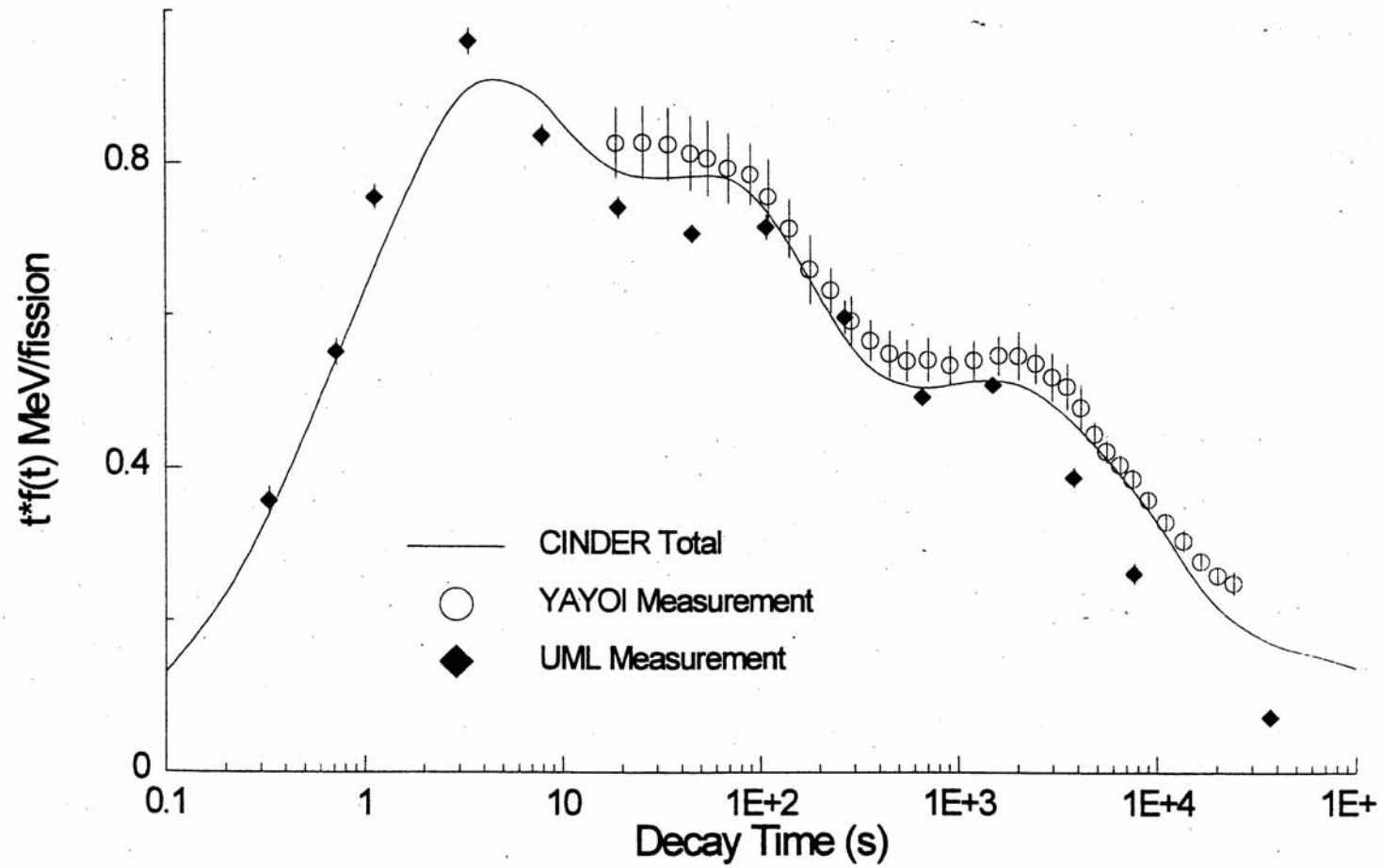
Response Function Fit of ^{235}U Decay Heat Gamma Spectrum



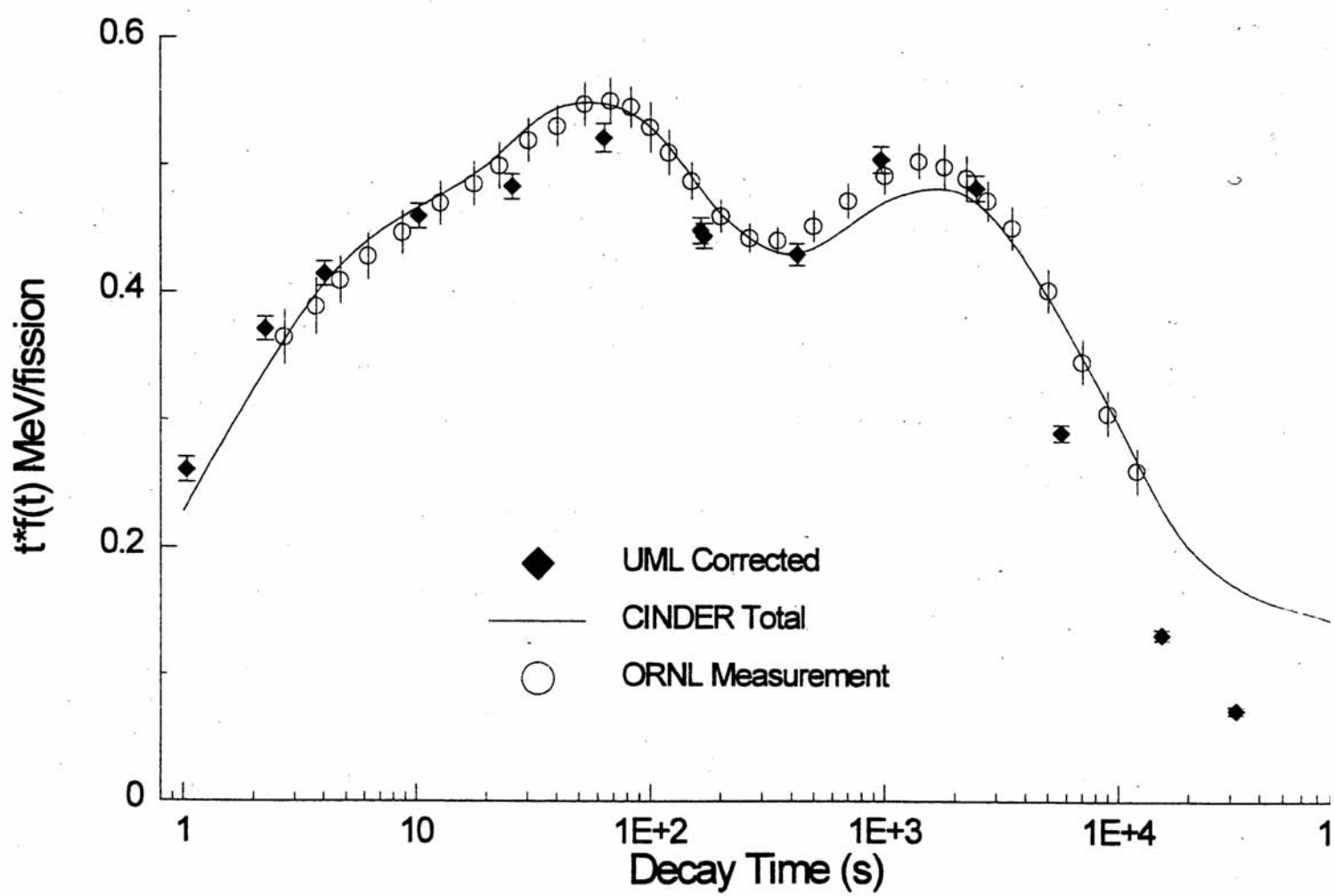
Gamma Decay Heat from ^{235}U Fission



Gamma Decay Heat from ^{238}U Fission



Gamma Decay Heat from ^{239}Pu Fission



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- Hung Nguyen
- Sameer Tipnis
- Nicholas Sampas
- Quazi Sharfuddin
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- Marcel Villani