Contributions to Nuclear Data by Radiochemistry Division, BARC

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Nuclear reaction data:

Users and experimentalists determining them

- Fission yield distribution in neutron induced fission of actinides (for nuclear data and understanding the factors influencing them)
- Mass, charge and angular distribution of fission products in heavy ion induced fission (understanding the mechanism of the reactions)
- Nuclear spectroscopy
- Neutron capture cross-section/gamma-ray production probabilities for analytical purposes

Facilities

Reactors

- APSARA
- CIRUS
- DHRUVA

neutrons

E_n=0-10 MeV

$\phi_n \cong 5\times10^{11}$ to 5×10^{13} n cm^{-2}s^{-1}

f = 20 TO 150

Accelerators

- BARC-TIFR Pelletron, Mumbai
- Variable Energy Cyclotron, Kolkata
- p, α and heavy ions

I $\cong$ nA to μA

E $\cong$3-8 MeV/A

Methodologies

Radiochemical method

- Irradiation followed by off-line γ-ray spectrometry

Induced activity at the end of irradiation

$$A = N\sigma\phi\left(1 - e^{-\lambda T_{irr}}\right)$$

	Reactor Irradiation	Beam Irradiation
N:	Total no. of target atoms	Target atoms per unit area
ϕ:	Flux (neutrons.cm^{-2}.sec^{-1})	Intensity (particles.sec^{-1})
σ:	Cross section	
T_{irr}:	Duration of irradiation	
λ:	Decay constant of product radionuclide	

- **Assay of gamma-ray activity after cooling time T_C**

$$Peak\ Area/s = N\lambda a_{\gamma}\varepsilon_{E}$$

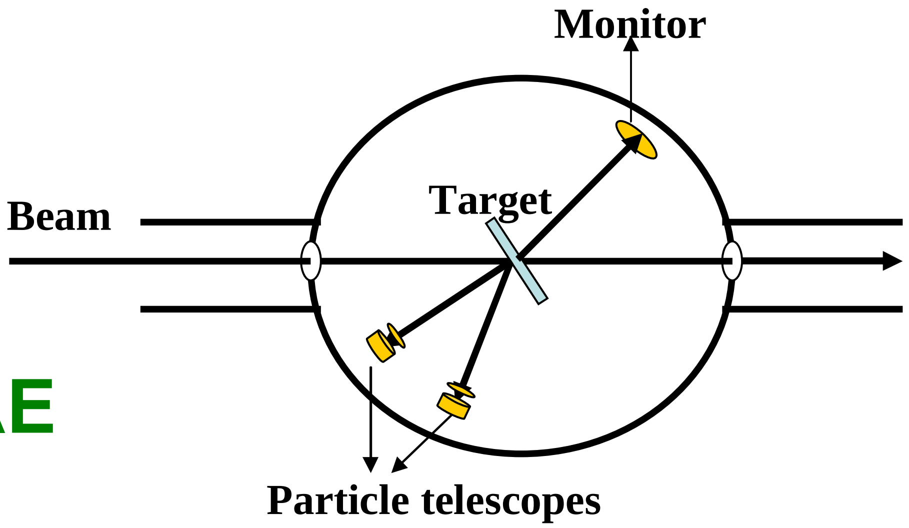
a_{γ} : Gamma-ray abundance

ε_E : Detection Efficiency

Peak area → Activity → Cross section

- **Coincident measurements**

- **Online charge particle measurement using E-ΔE detectors**



NUCLEAR FISSION STUDIES

Mass & Charge distribution in neutron induced fission of Actinides

^{238}U, ^{237}Np, $^{238\text{-}241}$Pu, ^{241}Am, ^{243}Am, $^{244\text{-}245}$Cm

Off-line gamma ray spectrometry

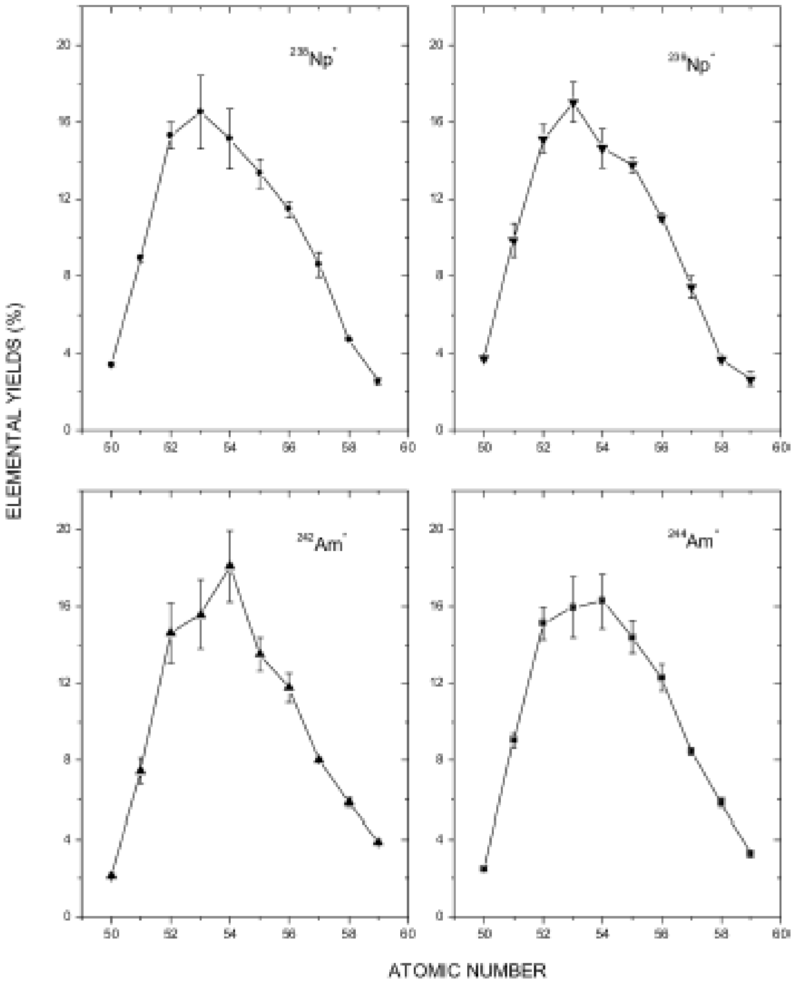
Radiochemical separations, in some cases

Nucl. Phys. A 781 (2007) 1

Nucl. Phys. A 612 (1997) 143

J. Phys. G. 30 (2004) 107

Eur. Phys. J. A 7 (2003) 495.



Elemental Yields in neutron induced fission

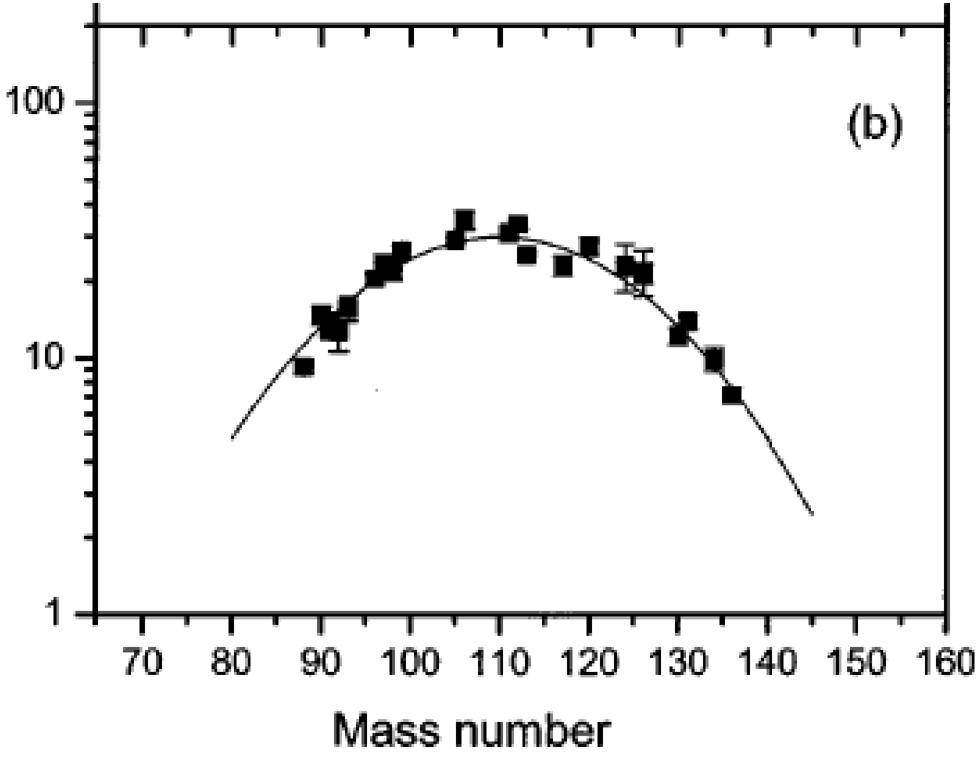
Heavy ion induced fission

- α, p induced fission
- Medium heavy ion induced fission

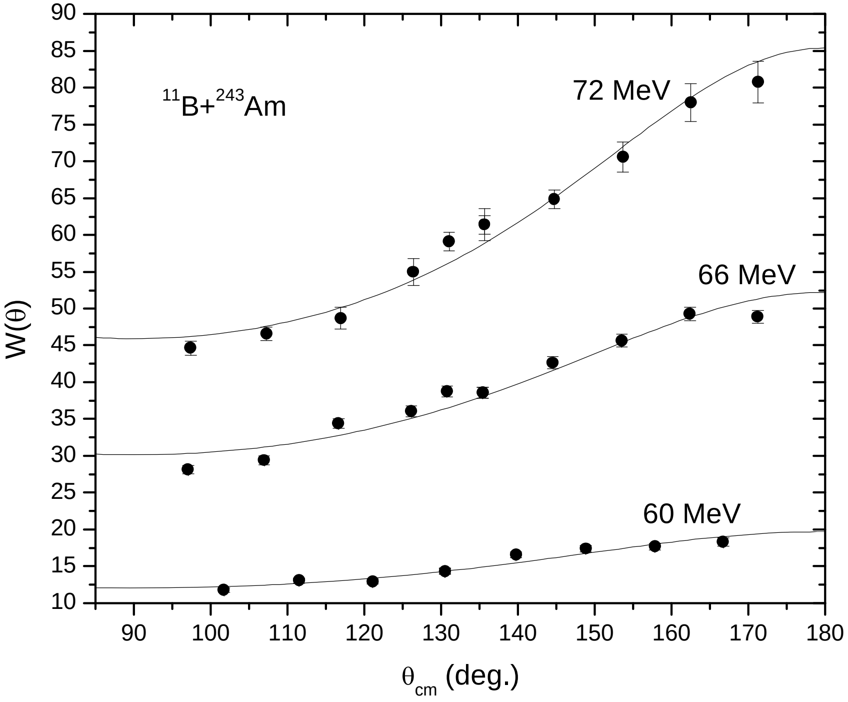
  (ion beams of isotopes of Li, B, C, O, Ne…)

- Both online and off-line measurements
- Mass, charge, angular and mass resolved angular distributions
- To investigate transfer induced fission
- To understand the correlation between mass asymmetry and angular anisotropy

Phys. Rev. C 71 (2005) 044616
Eur. Phys. A. 26 (2005) 1434
Phys. Rev.C, 74 (2006) 014610



^{20}Ne+^{208}Pb at 114 MeV



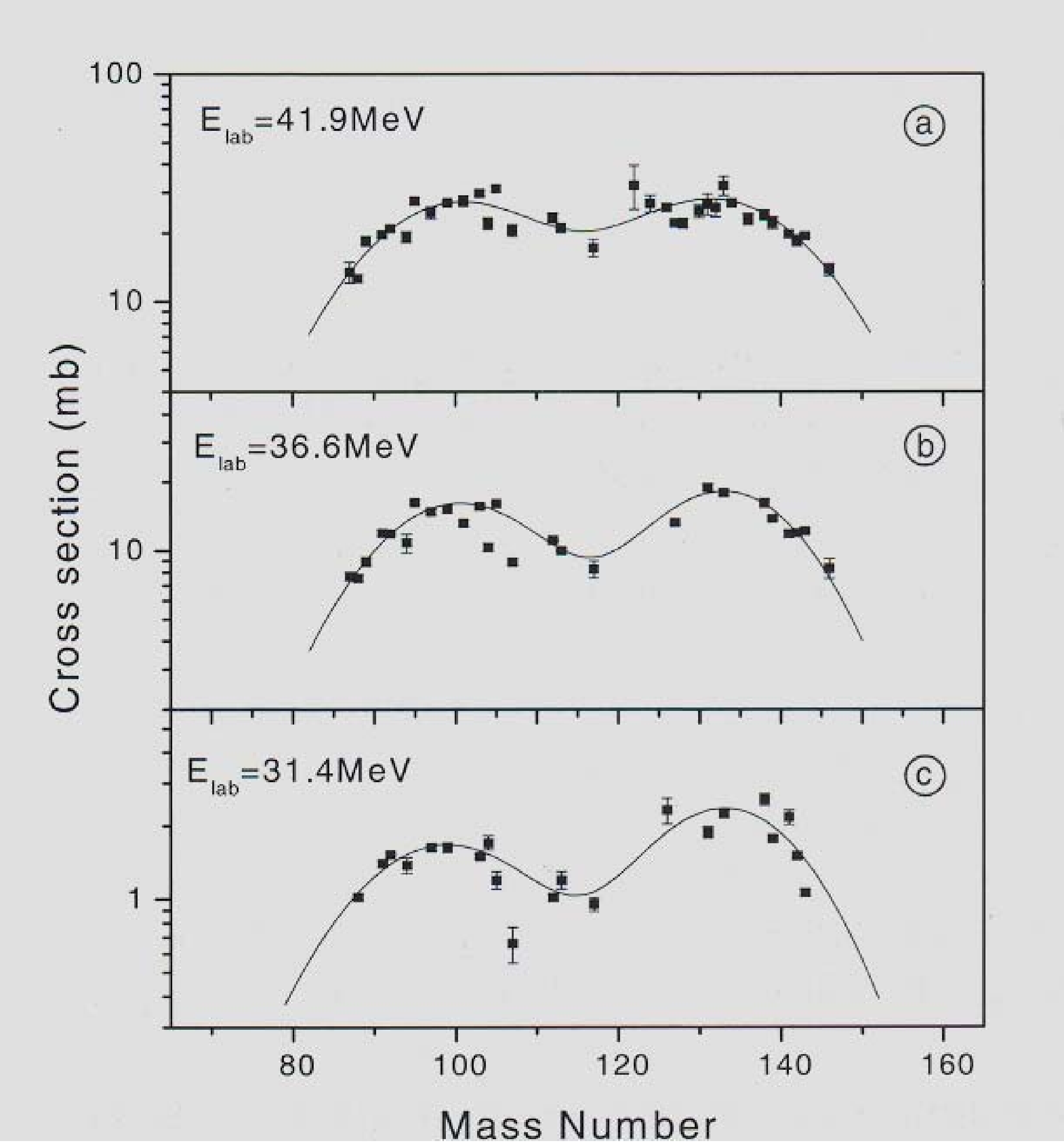
CM AD of fission fragments in ^{11}B+^{243}Am reaction

Phys. Rev. C 69 (2004)024613

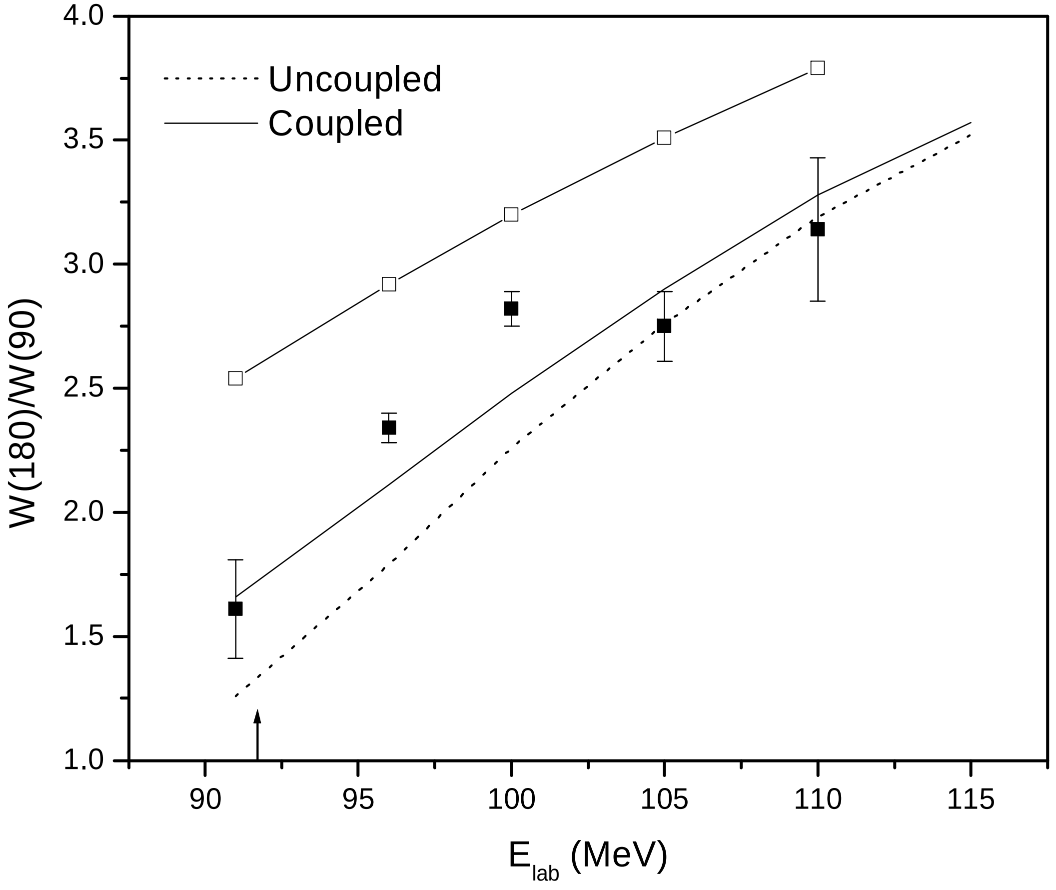
Phys. Rev. C 75 (2007) 024609

Mass distribution in ^{7}Li+^{232}Th

Radiochim. Acta. **90(4) (2002) 185.**



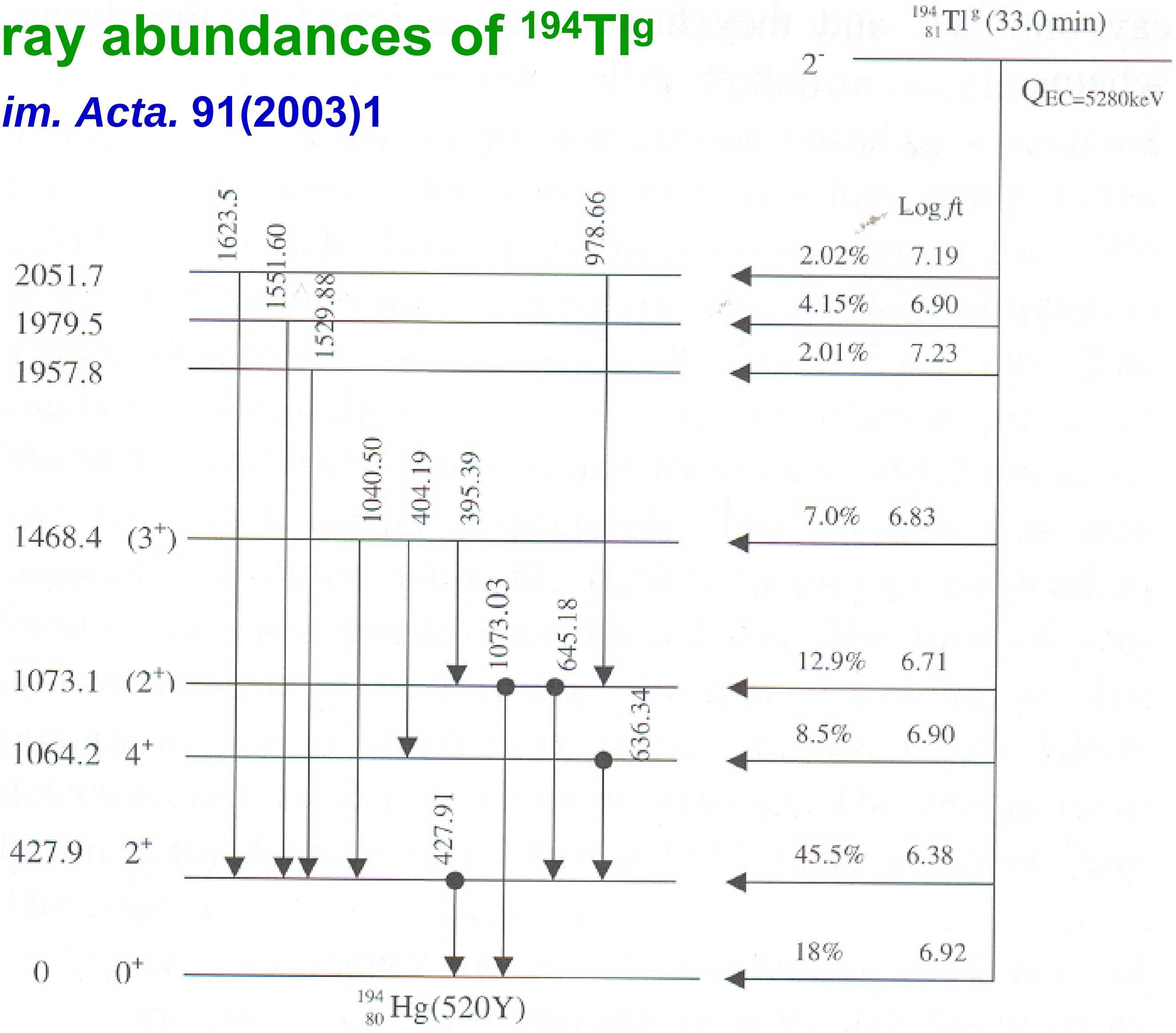
Angular anisotropy in ^{19}F+197^{Au}



Nuclear Spectroscopic Data

Gamma ray abundances of $^{194}Tl^{g}$

Radio. Chim. Acta. 91(2003)1



- **Gamma-ray abundance of capture γ-rays from 60Co**

Nucl. Instr. Meth. A. 457 (2001) 180.

Gamma ray abundances in the Alpha decay of ^{229}Th

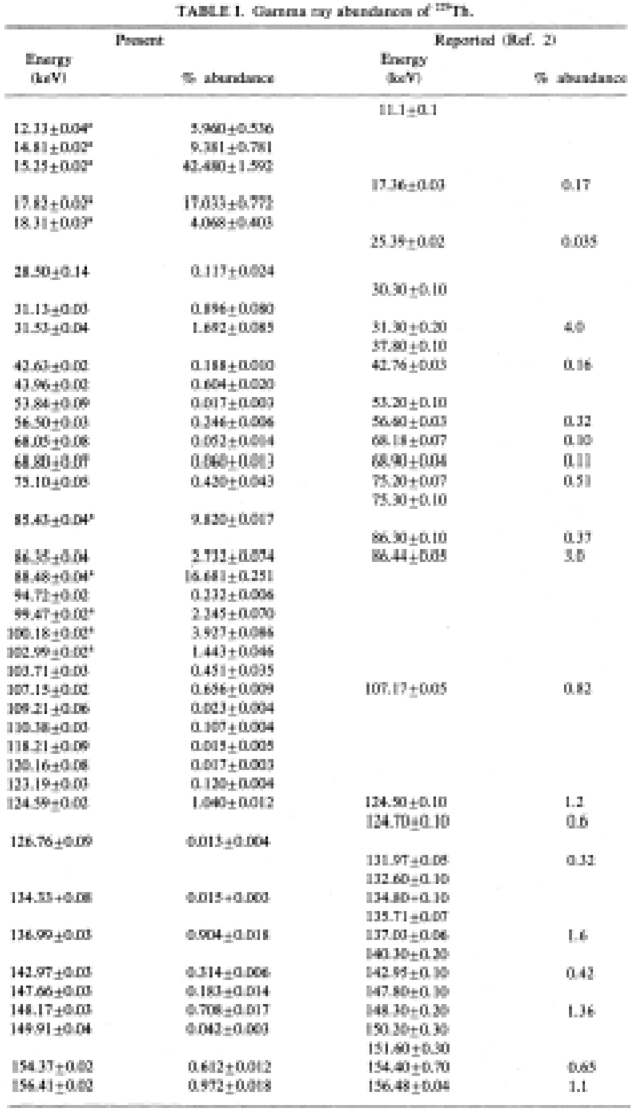


TABLE I. Gamma ray abundances of ^{229}Th.

Present		Reported (Ref. 2)	
Energy (keV)	% abundance	Energy (keV)	% abundance
		11.1±0.1	
12.33±0.04[a]	5.960±0.536		
14.81±0.02[a]	9.381±0.781		
15.25±0.02[a]	42.480±1.592		
		17.36±0.03	0.17
17.82±0.02[a]	17.033±0.772		
18.31±0.03[a]	4.068±0.403		
		25.39±0.02	0.035
28.50±0.14	0.117±0.024		
		30.30±0.10	
31.13±0.03	0.896±0.080		
31.53±0.04	1.692±0.085	31.30±0.20	4.0
		37.80±0.10	
42.63±0.02	0.188±0.010	42.76±0.03	0.16
43.96±0.02	0.604±0.020		
53.84±0.09	0.017±0.003	53.20±0.10	
56.50±0.03	0.246±0.006	56.60±0.03	0.22
68.05±0.08	0.052±0.004	68.18±0.07	0.10
68.80±0.07	0.060±0.013	68.90±0.04	0.11
75.10±0.08	0.420±0.043	75.20±0.07	0.51
		75.30±0.10	
85.43±0.04[a]	9.820±0.017		
		86.30±0.10	0.37
86.35±0.04	2.732±0.054	86.44±0.05	3.0
88.48±0.04[a]	16.681±0.251		
94.72±0.02	0.232±0.006		
99.47±0.02[a]	2.245±0.070		
100.18±0.02[a]	3.927±0.086		
102.99±0.02[a]	1.443±0.046		
103.71±0.03	0.451±0.035		
107.15±0.02	0.656±0.009	107.17±0.05	0.82
109.21±0.06	0.023±0.004		
110.38±0.03	0.107±0.004		
118.21±0.09	0.015±0.005		
120.16±0.08	0.017±0.003		
123.19±0.03	0.120±0.004		
124.59±0.02	1.040±0.012	124.50±0.10	1.2
		124.70±0.10	0.6
126.76±0.09	0.013±0.004		
		131.97±0.08	0.32
		132.60±0.10	
134.33+0.08	0.015+0.003	134.80+0.10	
		135.71±0.07	
136.99±0.03	0.904±0.018	137.03±0.06	1.6
		140.30±0.20	
142.97±0.03	0.314±0.006	142.95±0.10	0.42
147.66±0.03	0.183±0.014	147.80±0.10	
148.17±0.03	0.708±0.017	148.30±0.20	1.36
149.91±0.04	0.042±0.003	150.20±0.30	
		151.60±0.30	
154.37±0.02	0.612±0.012	154.40±0.70	0.63
156.41±0.02	0.972±0.018	156.48±0.04	1.1

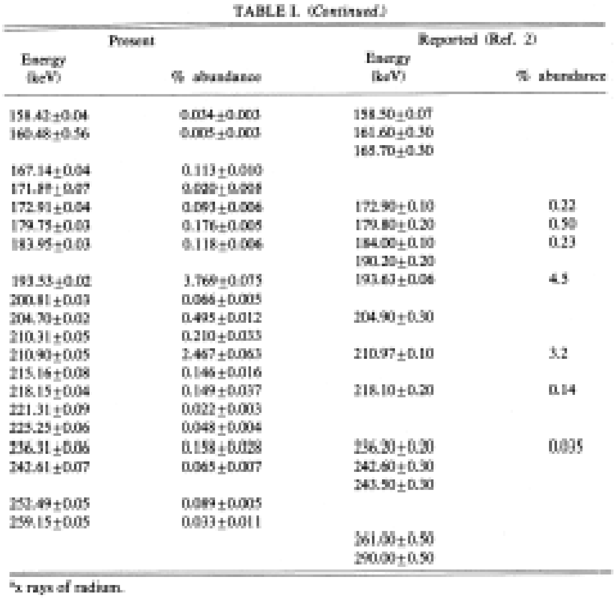


TABLE I. (Continued.)

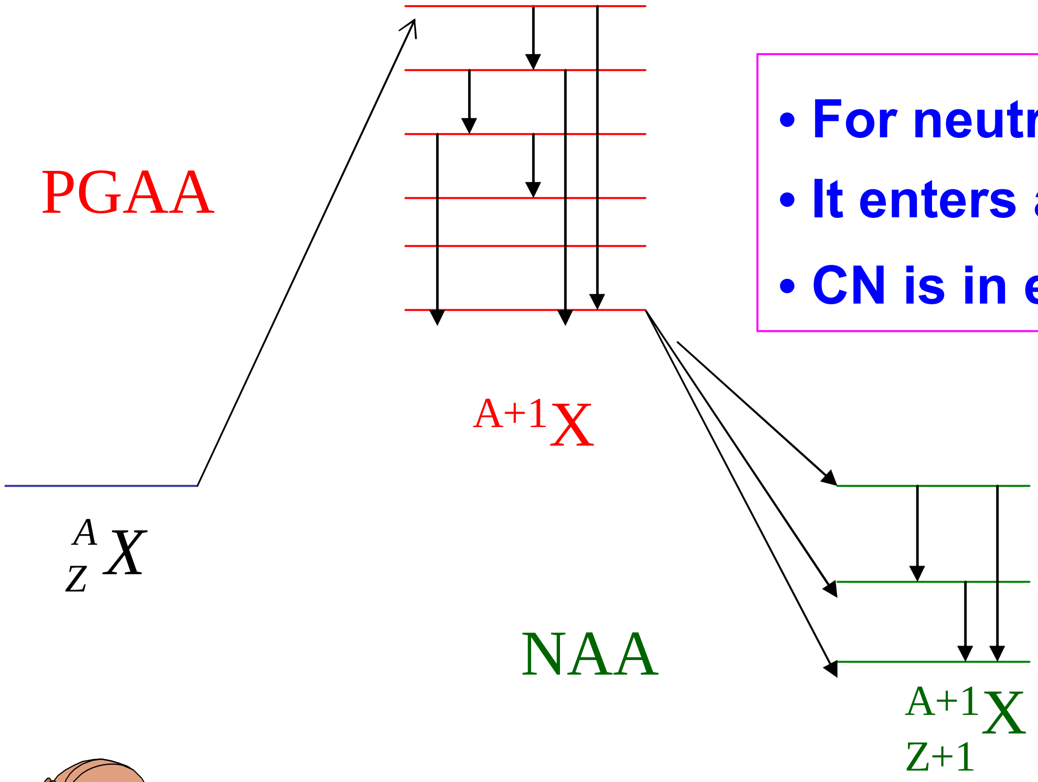
Present		Reported (Ref. 2)	
Energy (keV)	% abundance	Energy (keV)	% abundance
158.42±0.04	0.024±0.003	158.50±0.07	
160.48±0.56	0.005±0.003	161.60±0.30	
		165.70±0.30	
167.14±0.04	0.113±0.010		
171.89±0.07	0.020±0.008		
172.91±0.04	0.093±0.006	172.90±0.10	0.22
179.75±0.03	0.176±0.005	179.80±0.20	0.50
183.95±0.03	0.118±0.006	184.00±0.10	0.23
		190.20±0.20	
193.53±0.02	3.769±0.075	193.63±0.06	4.5
200.81±0.03	0.066±0.005		
204.70±0.02	0.495±0.012	204.90±0.30	
210.31±0.05	0.210±0.033		
210.90±0.05	2.467±0.063	210.97±0.10	3.2
215.16±0.08	0.146±0.016		
218.15±0.04	0.149±0.037	218.10±0.20	0.14
221.31±0.09	0.022±0.003		
225.25±0.06	0.048±0.004		
236.31±0.06	0.158±0.028	236.20±0.20	0.035
242.61±0.07	0.065±0.007	242.60±0.30	
		243.50±0.30	
252.49±0.05	0.089±0.005		
259.15±0.05	0.033±0.011		
		261.00±0.50	
		290.00±0.50	

[a] x rays of radium.

Phys. Rev. C. 27 (1983)327

Data use and determination for analytical purposes

NEUTRON ACTIVATION ANALYSIS



- For neutron induced reactions $V_C=0$
- It enters all nuclei and binds to it.
- CN is in excited state.

NEUTRON INTERACTION OFTEN PRODUCES RADIOISOTOPES : ENTIRE PERIODIC TABLE

CHARACTERISTIC RADIATIONS, e.g., GAMMA RAYS ARE MEASURED : CONCN. OF ISOTOPES (ELEMENTS)

STANDARDIZATION METHODS OF NAA

$$A = N\sigma\phi\,[1 - e^{-\lambda t_i}]e^{-\lambda t_c}$$

- Absolute method

- Relative method (comparative)
  Ratios of count rates in standard and sample

- Single comparator (k_0-method)
  Co-irradiation of sample with a mono standard (e.g., Au, Mn, Sc)

k_0-methodology & Calculations

Determination of α and f by cadmium ratio or bare detectors: ^{197}Au and ^{94,96}Zr

k_0- factors determined as well as computed

$$k_0(theor.) = \frac{M^*\theta\gamma\sigma_0}{M\theta^*\gamma^*\sigma_0^*}$$

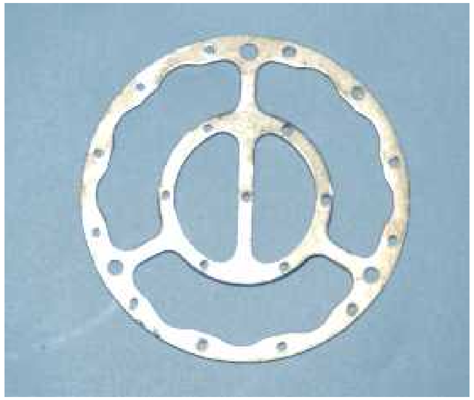
$$k_0(\exp) = \frac{A_{sp}}{A_{sp}^*}\cdot\frac{f+Q_0(\alpha)}{f+Q_0(\alpha)^*}\cdot\frac{\varepsilon}{\varepsilon^*}$$

$$C_i = \frac{A_{p,i}}{A_{sp}^*}\cdot\frac{1}{k_0}\cdot\frac{f+Q_0(\alpha)^*}{f+Q_0(\alpha)}\cdot\frac{\varepsilon^*}{\varepsilon}$$

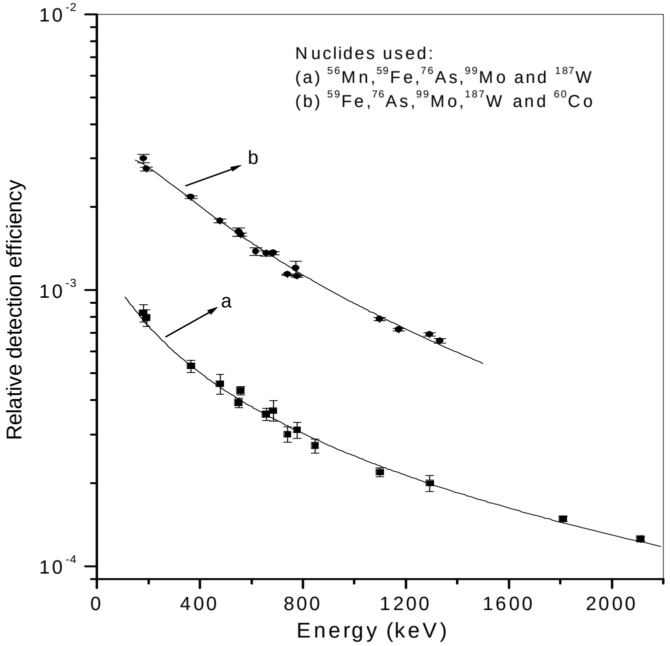
J. Radioanal. Nucl. Chem 256 (2003) 93
Anal. Chem.75(2003)4868
J. Nucl. Mat 326 (2004) 80
Anal. Chim. Acta 522(2004)127
Appl. Radiat. Isot. 65(2007)164

In-situ efficiency calibration – Determination of relative amounts without use of standard

$$\frac{W_a}{W_s} = \frac{1}{k_{0,a}} \frac{A_{sp,a}}{A_{sp,s}} \frac{\left(f + Q_{0,s} \right)}{\left(f + Q_{0,a} \right)} \frac{\varepsilon_{E_a}}{\varepsilon_{E_s}}$$



Standard-less composition analysis of nuclear cladding materials: Zircaloy 2 and 4, Stainless Steel and 1S-Aluminium



In-situ relative detection efficiency using neutron activated SS 316M

Prompt gamma-ray Neutron Activation Analysis

$$R(CPS) = \frac{W\theta_i N_0 \sigma_i \phi a_\gamma \varepsilon_\gamma}{M}$$

$$k_{0,c}(x) = \frac{\left(\frac{A_{sp}}{\varepsilon}\right)_x}{\left(\frac{A_{sp}}{\varepsilon}\right)_c} = \frac{M_c(\theta\sigma a)_x}{M_x(\theta\sigma a)_c}$$

J. Radioanal. Nucl. Chem 250 (2001) 303, NUcl. Instr. Meth.A 457 (2001) 180, Anal. Chim. Acta 535 (2004) 309, Anal. Chim. Acta 595 (2005) 2005

THANK YOU