RI Yields for OMC4DBD Offline Measurement

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OMC4DBD Collaboration meeting

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Outline

- Analysis of ^{24}Mg, ^{82}Kr and ^{130}Xe (Oct-Nov 2019)
  - Setup, calibration and detector efficiency
  - Gamma spectrum for ^{24}Mg, ^{82}Kr and ^{130}Xe
  - N(X') and R(X') for ^{24}Mg, ^{82}Kr and ^{130}Xe
- Expected RI gamma rays for ^{Nat}Ba and ^{136}Ba targets.
- OMC4DBD beamtime (Oct-Nov 2021)
  - Experimental setup and estimation

Muon irradiation PSI

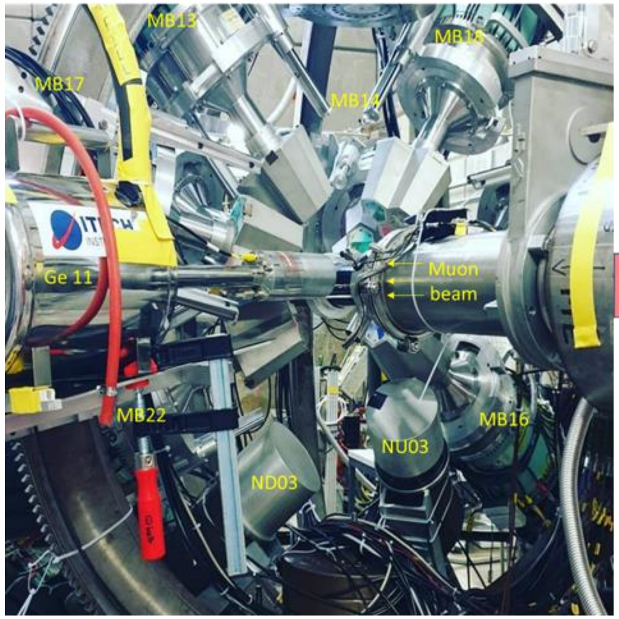
μ^- momentum @E2 beamline: 28 MeV/c

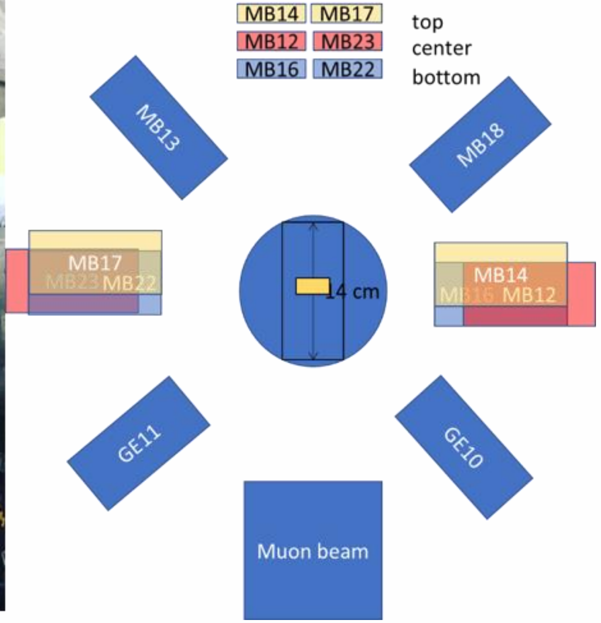
Irradiation time

^{24}Mg (15 October to 17 October 2019)

^{82}Kr (17 October to 23 October 2019)

^{130}Xe(17 October to 23 October 2019)



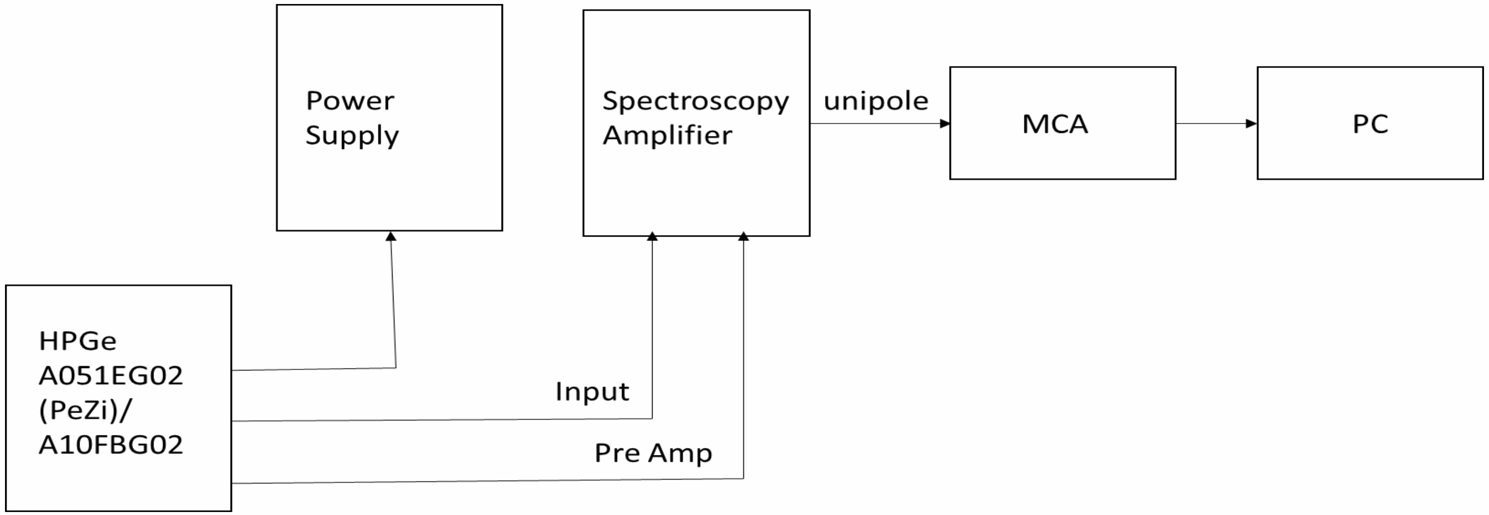


8 mini ball detector with FADC

To measure x-ray and gamma ray

Isotope	^{24}Mg	^{82}Kr	^{130}Xe
Type	Metal	Gas	Gas
Density	1.738 g/cm^3	2.413 g/cm^3	0.005887 g/cm^3
Enrichment	99.85%	99.946%	99.964%
Abundance	99.85% ^{24}Mg 0.08% ^{25}Mg 0.07% ^{26}Mg	0.004% ^{78}Kr 0.004% ^{80}Kr 99.946% ^{82}Kr 0.038% ^{83}Kr 0.004% ^{84}Kr 0.004% ^{86}Kr	0.001% ^{124}Xe 0.001% ^{126}Xe 0.001% ^{128}Xe 0.0163% ^{129}Xe 99.964% ^{130}Xe 0.0137% ^{131}Xe 0.001% ^{132}Xe 0.001% ^{134}Xe 0.001% ^{136}Xe

Delayed Gamma Measurement setup @PSI

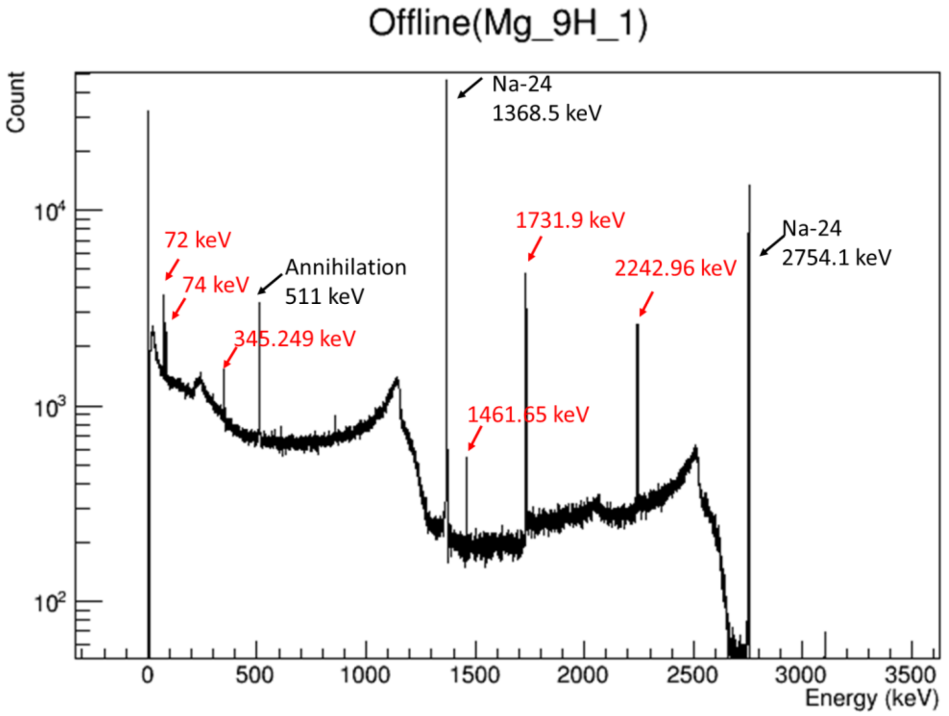


A051EG02(PeZi)

A10F8G02

Detector	Energy calibration	Detector calibration
^{24}Mg(46.25hours) A051EG02(PeZi)	$E = -1.469\times10^{-1} + 4.023\times10^{-1}\times Ch$	$In(Eff) = (-2.486\times10^{2}) + (2.329\times10^{2}\times In(E)) - (9.125\times10^{1}\times In(E)^{2}) + (1.907\times10^{1}\times In(E)^{3}) - (2.252\times10^{0}\times In(E)^{4}) + (1.423\times10^{-1}\times In(E)^{5}) - (3.753\times10^{-3}\times In(E)^{6})$
^{82}Kr(91.8hours) A10F8G02 ^{130}Xe(195.29hours)	$E = -2.309\times10^{0} + 3.595\times10^{-1}\times Ch$	$In(Eff) = (-4.132\times10^{1}) + (2.51\times10^{1}\times In(E)) - (5.749\times10^{0}\times In(E)^{2}) + (5.571\times10^{-1}\times In(E)^{3}) - (2.002\times10^{-2}\times In(E)^{4})$

Gamma Spectrum of ^{24}Mg

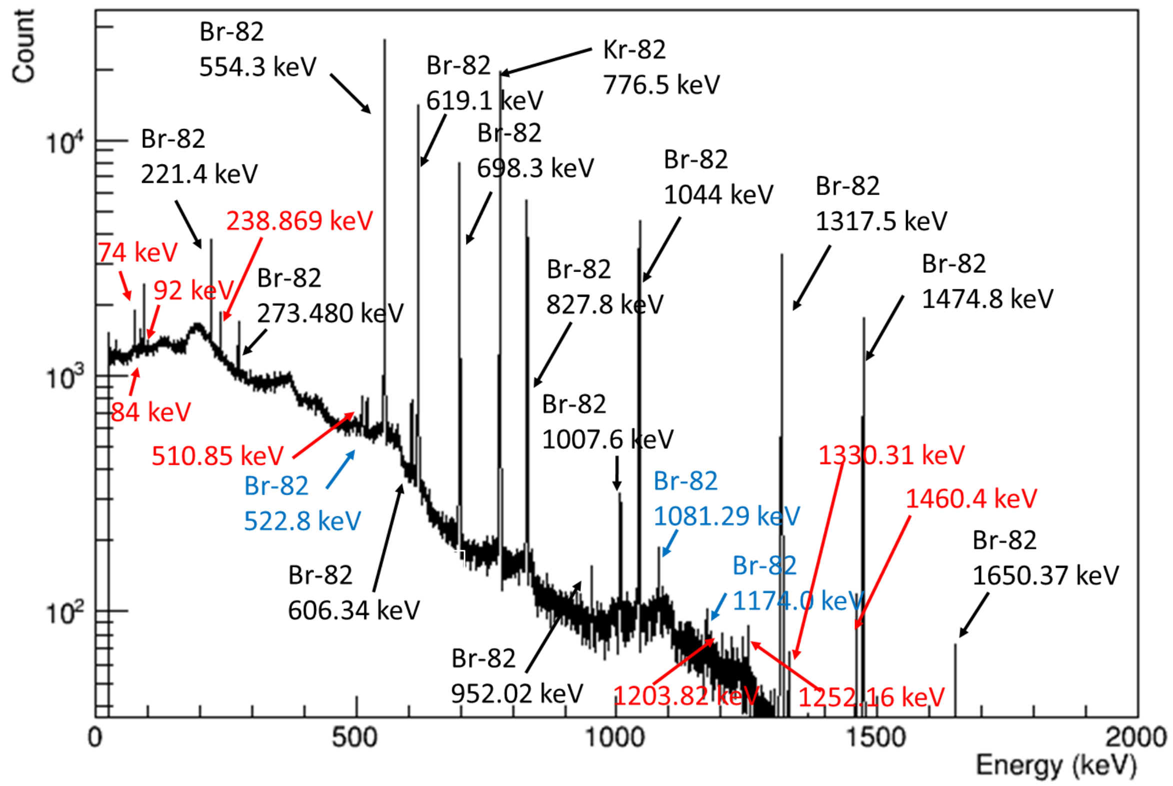


*3 old energy
*6 pending energy

Isotope	Energy (keV)	N(X')	R(X')
^{24}Mg(μ, 0n) ^{24}Na	1368.5	1.93E11	7.12E12
	2754.1	2.23E11	7.69E12
	511	N/A	N/A

1731.9 keV - single escape peak
2242 keV - double escape peak
72,74 keV - Ge peak

Gamma Spectrum of ^{82}Kr

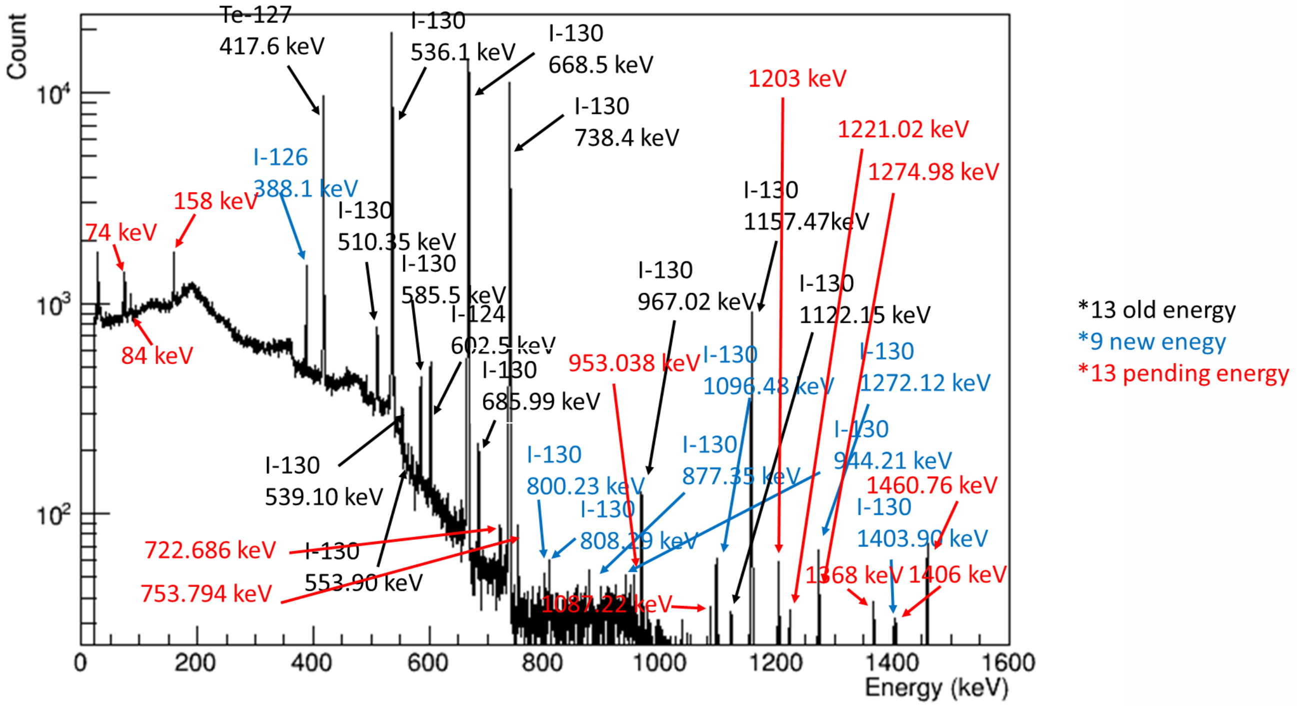


*14 old energy
*3 new enegy
*9 pending energy

However, for the small peak which is 6.13 m half life the decay curve was excluded. (606.3 keV, 952.0 keV, 1007.6 keV, 1650.4 keV.)

Isotope	Energy (keV)	N(X')	R(X')
^{82}Kr(μ, 0n) ^{24}Br	221.4	1.04E7	7.92E8
	273.5	6.08E5	4.32E7
	554.3	2.21E8	1.59E10
	619.1	6.53E7	4.33E9
	698.3	2.23E7	1.64E9
	776.5	1.29E7	9.37E8
	827.8	1.99E7	1.43E9
	1044.0	2.33E7	1.71E9
	1317.5	4.20E7	3.08E9
	1474.8	2.70E6	1.98E8

Gamma Spectrum of ^{130}Xe



Isotope	Energy (keV)	N(X’)	R(X’)
$^{130}Xe(\mu, 0n)$ ^{130}I	417.6	1.19E5	3.64E6
	510.4	3.98E5	4.69E7
	536.1	4.23E7	1.33E9
	539.1	2.92E5	4.23E6
	553.9	1.57E5	3.16E6
	585.5	7.51E5	2.17E7
	602.5	3.71E5	3.95E7
	668.5	4.30E7	1.32E9
	686.0	4.87E5	1.41E7
	738.4	3.76E7	1.18E9
	967.0	5.28E5	1.27E7
	1157.5	5.64E6	1.79E8

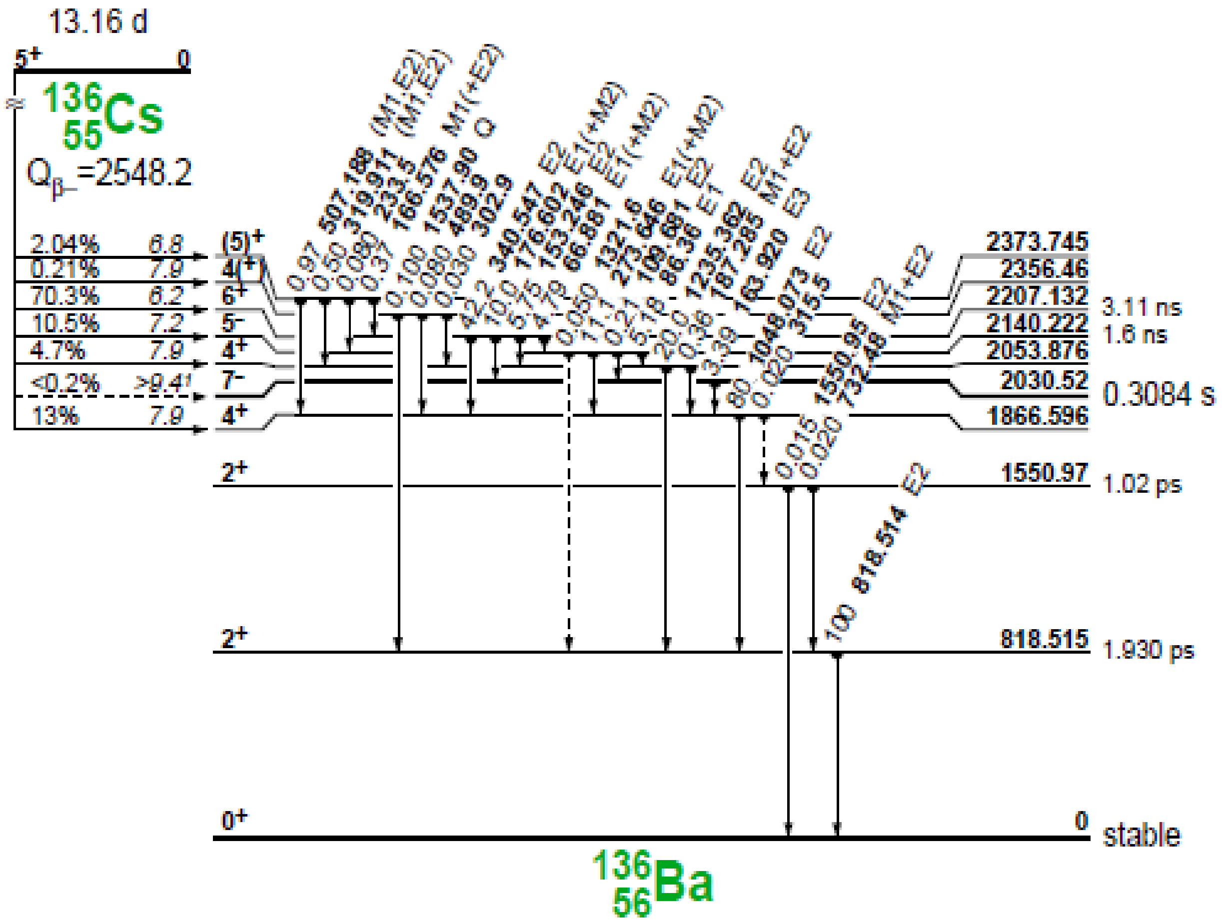
However, for the small peak which is 9 m half life the decay curve was excluded. (1122.15 keV)

Conclusion from offline measurement for OMC4DBD@PSI2019

- The RI gamma rays observed in offline are mostly from 0 neutron emission.
  - Gamma rays from other reaction channels have half life of within few seconds to few minutes.
  - Time taken for transferring target to offline measurement facility is about 30 minutes, thus the next beamtime should consider measuring RI gamma in online setup for 1 or 2 hours.
  - No gamma rays accompanying alpha emission is observed for ^{24}Mg target.
- The N(X') for ^{24}Mg, ^{82}Br and ^{130}Xe are in order of $10^5 - 10^{11}$
- The R(X') for ^{24}Mg, ^{82}Br and ^{130}Xe are in order of $10^6 - 10^{12}$

OMC4DBD beamtime (Oct-Nov 2021)

- Targets:
  - ^{136}Ba (Enrichment: 95.27%)
  - ^{Nat}Ba (Enrichment: ^{132}Ba(0.1%) , ^{134}Ba(2.42%), ^{135}Ba(6.59%), ^{136}Ba(7.85%), ^{137}Ba(11.23%), ^{138}Ba(71.70%)
  - For medium-heavy nuclei up to 5 neutrons emission are expected from ${}^{A}_{Z}Ba + \mu^{-} \rightarrow {}^{A-x}_{Z-1}Cs + xn + \overline{\nu_{\mu}}$ where x = 0, 1, 2, … 5 and 1 proton emission are expected from ${}^{A}_{Z}Ba + \mu^{-} \rightarrow {}^{A-y}_{Z-1-y}Xe + {}^{1}_{1}p + \overline{\nu_{\mu}}$ where y = 0, 1 or 2.



https://www.nndc.bnl.gov/ensnds/136/Ba/beta_decay_13.01_d.pdf

Firestone, R. B., Shirley, V. S., Baglin, C., Franck, C., & Ziplin, J. (1996). Table of Isotopes, eight edition. *CD–ROM edition, version, 1*.

Expected gamma ray from ^{136}Ba and ^{Nat}Ba

Isotope(half-life)	Energy	Intensity	Mode
138Cs(33.41m)	112.6	0.13	β- Decay
	138.1	1.49	
	191.96	0.5	
	193.89	0.328	
	212.32	0.175	
	227.76	1.51	
	324.9	0.29	
	333.86	0.089	
	363.93	0.244	
	365		
	408.98	4.66	
	421.59	0.429	
	462.796	30.7	
	516.74	0.43	
	547.001	10.76	
	575.7	0.021	
	683.59	0.108	
	773.31	0.233	
	782.08	0.33	
	871.8	5.11	
	880.8	0.11	
	953	0.053	
	1009.78	29.8	
	1147		
	1203.69	0.4	
	1343.59	1.14	
	1415.68	0.37	
	1435.795	76.3	
	1445.04	0.97	
	1495.63	0.18	
	1555.31	0.366	
	1614.09	0.137	
	2218	15.2	
	2583.15	0.239	
	2639.59	7.63	
	2931.4	0.02	
	3049.9	0.0031	

Isotope(half-life)	Energy	Intensity	Mode
138Cs(2.91m)	79.9	100	EC Decay
138Cs(2.91m)	107.7	0.19	β- Decay
	112.6	1.52	
	191.96	15.4	
	212.32	0.53	
	324.9	1.18	
	408.98	~0.09	
	462.796	18.6	
	871.8	~0.15	
	1435.795	19	
	516.74	0.61	

^{136}Ba(μ,0n) ^{136}Cs

Isotope(half-life)	Energy	Intensity	Mode
136Cs(13.16d)	66.881	4.79	β- Decay
	86.36	5.18	
	109.681	0.21	
	153.246	5.75	
	163.92	3.39	
	166.576	0.37	
	176.602	10	
	187.285	0.36	
	233.5	0.08	
	273.646	11.1	
	302.9	0.03	
	315.5	0.02	
	319.911	0.5	
	340.547	42.2	
	489.9	0.08	
	507.188	0.97	
	732.48	0.02	
	818.514	100	
	1048.073	80	
	1235.362	20	
	1321.6	0.05	
	1537.9	0.1	
	1550.95	0.015	

^{136}Ba(μ,1n) ^{135}Cs

Not observed ;(2.3x10^6y)

^{136}Ba(μ,2n) ^{134}Cs

Not observed ;(2.062y)

^{136}Ba(μ,3n) ^{133}Ba

Not observed ;(10.52y)

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Expected gamma ray from ^{136}Ba and ^{Nat}Ba

$^{136}Ba(\mu,4n)^{132}Cs$

Isotope(half-life)	Energy	Intensity	Mode
132Cs(6.479d)	464.55	1.73	β- Decay
	567.14	0.234	
	1031.7	0.125	
	363.34	0.0683	EC Decay
	505.79	0.73	
	630.19	0.95	
	667.718	98	
	687.74	0.0021	
	772.6	0.072	
	1136	0.476	
	1297.91	0.055	
	1317.927	0.585	
	1985.638	0.07	

$^{135}Ba(\mu,5n)^{130}Cs$

Isotope(half-life)	Energy	Intensity	Mode
130Cs(3.46m)	536.09	34.7	EC Decay
	586.05		
	510.35		
	470.8	3	
	206.6	0.58	
130Cs(29.21m)	536.09	3.8	EC Decay
	586.05	0.47	
	671.9	0.012	
	894.5	0.39	
	1028.11	0.017	
	1122.15	0.073	
	1257.5	0.077	
	1263.8	0.038	
	1380.15	0.007	
	1481.8	0.023	
	1614.1	0.26	
	1687.4	0.192	
	1707	0.138	
	1794		
	1850.5	0.031	
	1958.02	0.017	
	1966.04	0.009	
	1997.3	0.17	
	2016		
	2092.29	0.013	
	2150.15	0.012	
130Cs(3.46m)	14.9	0.0000049	IT Decay
	31.5	0.07	
	82.9	13	
130Cs(29.21m)	80.45	680	IT Decay
	51.18	138	
	131.5	25.4	
	148.35	100	

$^{134}Ba(\mu,5n)^{129}Cs$

Isotope(half-life)	Energy	Intensity	Mode
129Cs(32.06h)	36.578	2.97	EC Decay
	89.79	0.0024	
	93.329	0.652	
	177.036	0.269	
	266.82	0.272	
	270.352	0.2127	
	278.614	1.32	
	282.131	0.242	
	302.6	<0.00031	
	318.18	2.45	
	321.7	0.07	
	321.79	0.07	
	357.518	0.0058	
	371.918	30.6	
	373.36	0.012	
	411.49	22.31	
	492.781	0.0113	
	533.1	0.00095	
	534.546	0.0211	
	548.945	0.603	
	572.6	0.002	
	582.6	0.0009	
	585	0.0005	
	586.111	0.0129	
	624.312	0.0282	
	627.884	0.0017	
	904.306	0.0083	
	906.425	0.22	
	946.046	0.0695	

Expected gamma ray from ^{136}Ba and ^{Nat}Ba

^{136}Ba(μ,1p) ^{135}Xe

Isotope(half-life)	Energy	Intensity	Mode
135Xe (15.29m)	786.836	0.004	β- Decay
	1133	0.00028	
	1192.2	0.00003.7	
	1358	0.00018	
135Xe (9.14h)	200.19	0.012	β- Decay
	249.77	90	
	358.384	0.221	
	373.13	0.015	
	408.009	0.359	
	454.2	0.0036	
	573.36	0.0048	
	606.151	2.9	
	654.298	0.0451	
	731.634	0.055	
	812.635	0.0704	
	1062.41	0.0041	
135Xe (15.29m)	526.561	80.5	IT Decay

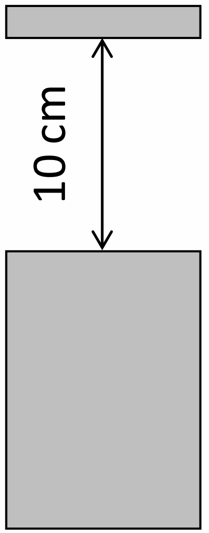
^{136}Ba(μ,2p) ^{134}Xe

Isotope(half-life)	Energy	Intensity	Mode
134Xe(290ms)	234.3	68	IT Decay
	847.025	100	
	884.09	94	

^{136}Ba(μ,3p) ^{133}Xe

Isotope(half-life)	Energy	Intensity	Mode
133Xe (5.243d)	76.623	0.27	β- Decay
	80.997	38	
	160.613	0.066	
	223.234	0.00012	
	302.853	0.0048	
	383.851	0.0024	
133Xe (2.19d)	233.221	10	IT Decay

Offline Experimental setup and estimation



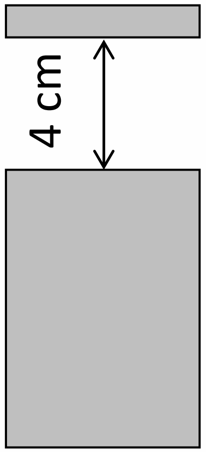
Online setup

N_μ=1 x 10^8/sec total μ at target

$Y_\gamma = N_\mu\, \varepsilon\, \eta\, t\, m$

ε = γ peak efficiency @500 keV = 2.97x10^{-2}
η= μ stopping probability = 1.0
m = gamma multiplicity =3(^{Nat}Ba)

- From calculation at 10 cm distance from HPGe window (500 keV), we will obtain 8.91M counts/sec for ^{Nat}Ba .
- We can get 32.1G counts/hour for ^{Nat}Ba target and ^{136}Ba
- Recommended 2 hours for ^{Nat}Ba target and 2 hours for ^{136}Ba



Offline setup

N_μ=6 x 10^4/sec total μ at target

$Y_\gamma = N_\mu\, \varepsilon\, \eta\, t\, m$

ε = γ peak efficiency @500 keV = 2.97x10^{-2} (tukar lg 1)
η= μ stopping probability = 1.0
m = gamma multiplicity = 3

- From calculation at 4 cm distance from HPGe window (500 keV), we will obtain 5.35k counts/sec.
- We need 19.3M counts/hour for ^{Nat}Ba target and for ^{136}Ba
- Recommended 20 days for ^{Nat}Ba target and 20 days for ^{136}Ba