LONG-LIVED NUCLEAR GAMMA RAYS FROM ORDINARY MUON CAPTURE ON ^{136}Ba AND ^{Nat}Ba

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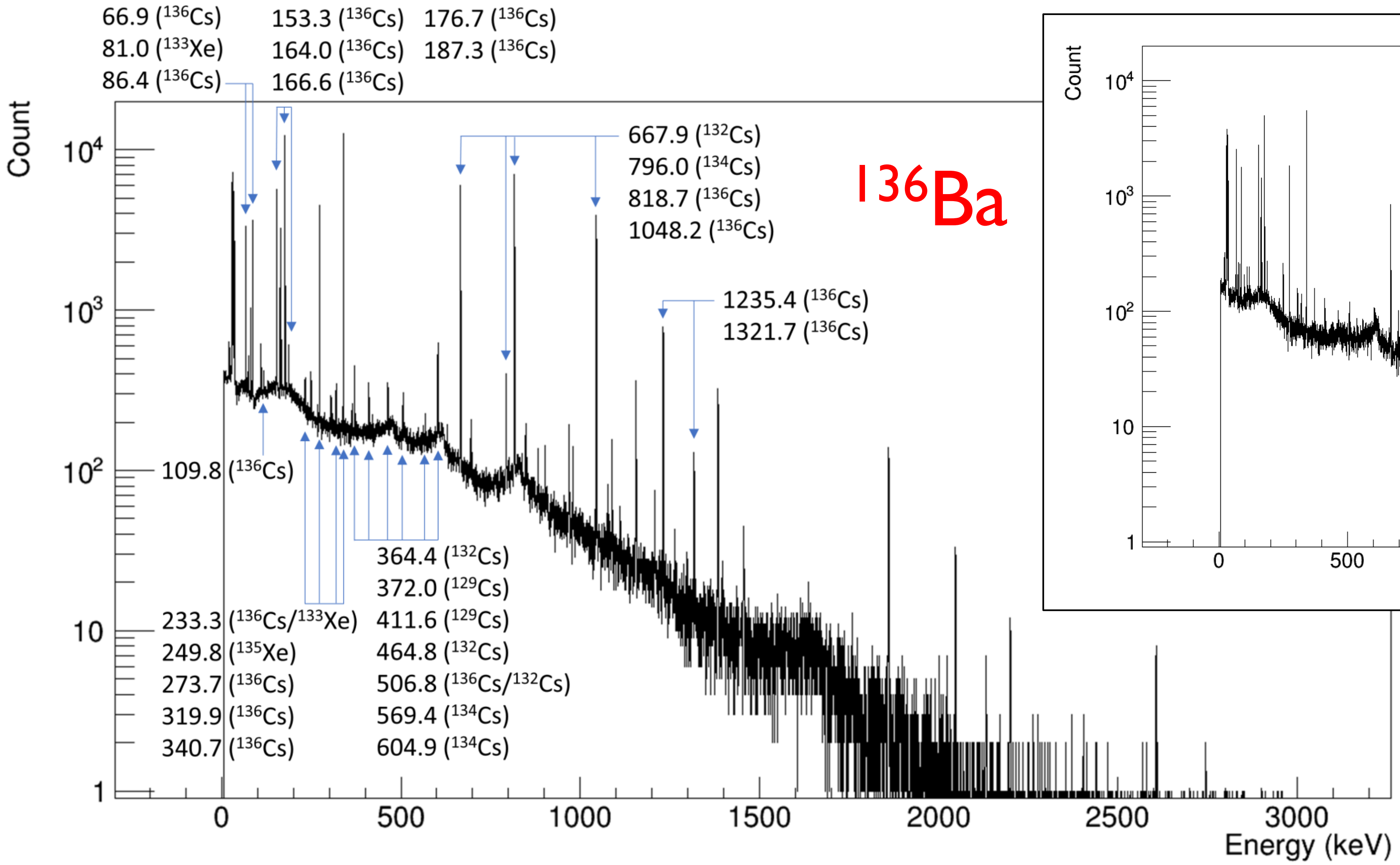
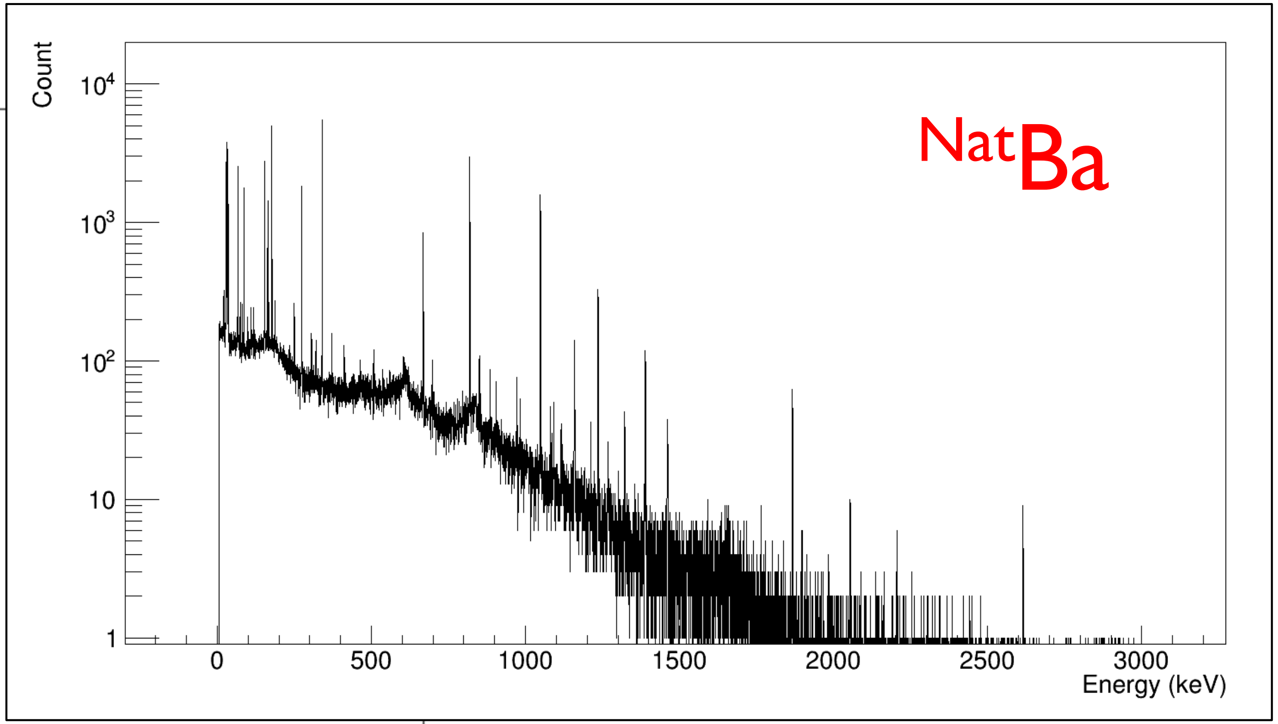
OMC4DBD GENERAL COLLABORATION MEETING

IRRADIATION AND MEASUREMENT SUMMARY

Target	**^{136}Ba**	**^{Nat}Ba**
Sample form	$^{136}BaCO_3$ powder	$^{Nat}BaCO_3$ powder
Mass	2 g	2 g
Diameter	20 mm	20 mm
Thickness	~ 4 mm	~ 4 mm
Muon momentum	38 MeV/c	31.5 – 42.5 MeV/c
Irradiation time	~ 138 hours	~ 68 hours
Time between beam stop and offline measurement	22 hours	25.5 hours
Offline measurement time	168.5 hours	211.5 hours

FULL SPECTRUM PER HOUR FROM ^{136}Ba AND ^{Nat}Ba OFFLINE MEASUREMENT





OBSERVED DECAY GAMMA PEAKS OF RESIDUAL ISOTOPES (RI) FROM ^{136}Ba

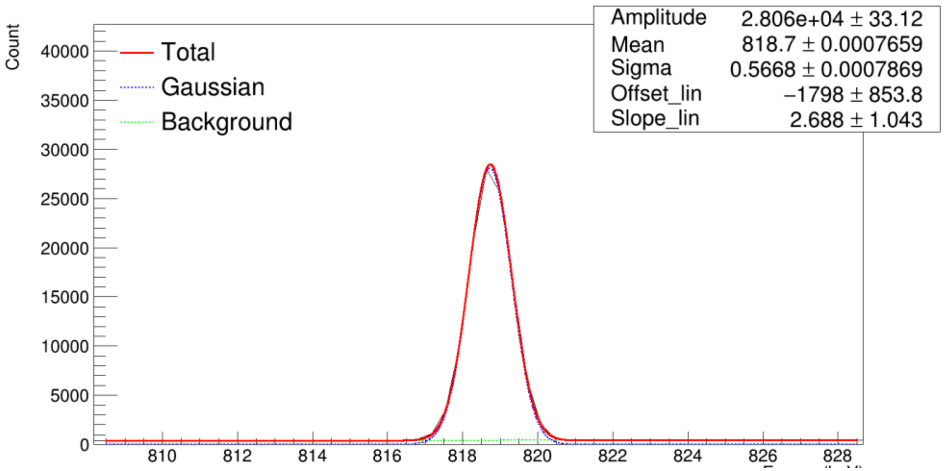
RI	Energy (keV)	Half-life
^{136}Cs	66.9 (4.8%), 86.4 (5.9%), 109.7 (0.41%), 153.2 (7.7%), 163.9 (4.7%), 166.6 (0.63%), 176.6 (13.7%), 187.3 (0.54%), 273.6 (12.7%), 319.9 (0.5%), 340.5 (46.8%), *507.2 (1%)*, 818.5 (99.7%), 1048.1 (80%), 1235.4 (20%), *1321.6 (0.05%)*	13.01 days
^{135}Cs	short half-life	
^{134}Cs	*563.2 (8.3%), 569.3 (15.4%), 604.7 (97.6%), 795.9 (85.5%), 802.0 (8.7%), 1365.2 (3%)*	*2.07 years*
^{133}Cs	stable	

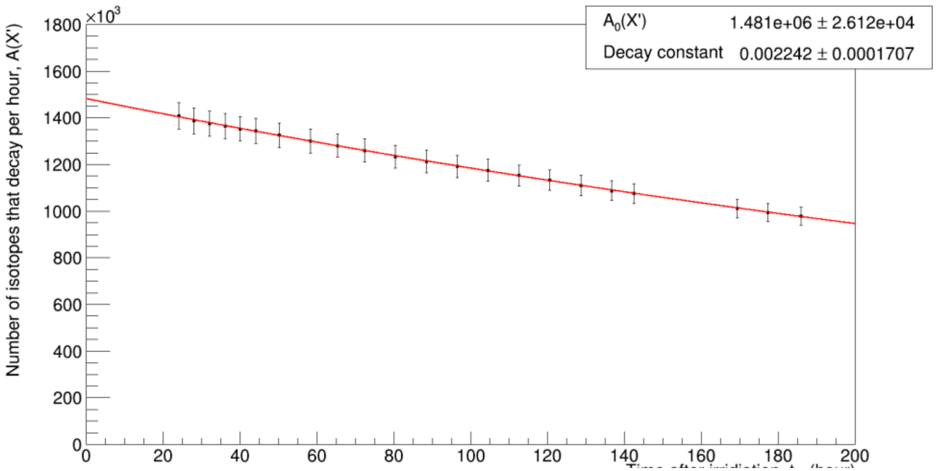
RI	Energy (keV)	Half-life
^{132}Cs	464.5 (1.6%), *505.8 (0.73%)*, 630.2 (0.95%), 667.7 (97.59%), 1317.9 (0.59%)	6.48 days
^{131}Cs	no gamma decay	
^{130}Cs	short half-life	
^{129}Cs	371.9 (30.6%), 411.5 (22.3%)	32.06 hours
^{135}Xe	249.8 (90%)	9.14 hours
^{134}Xe	extremely long half-life	
^{133}Xe	81.0 (36.9%), 233.2 (10.1%)	2.2, 5.25 days
^{132}I	dominated by ^{136}Cs	
^{131}I	364.5 (81.5%)	8.03 days

Red label: excluded from further analysis (due to large errors on peak or decay curve fitting)

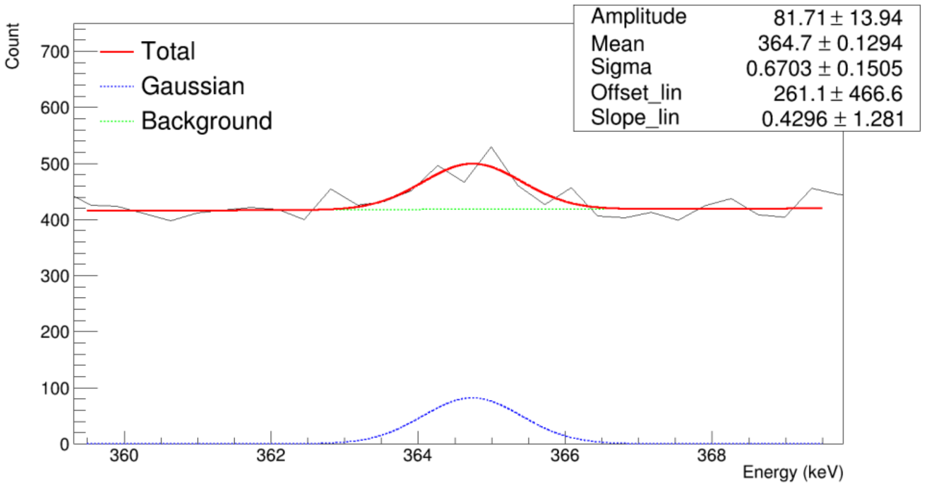
EXAMPLES OF PEAK FROM RI OF ^{136}Ba

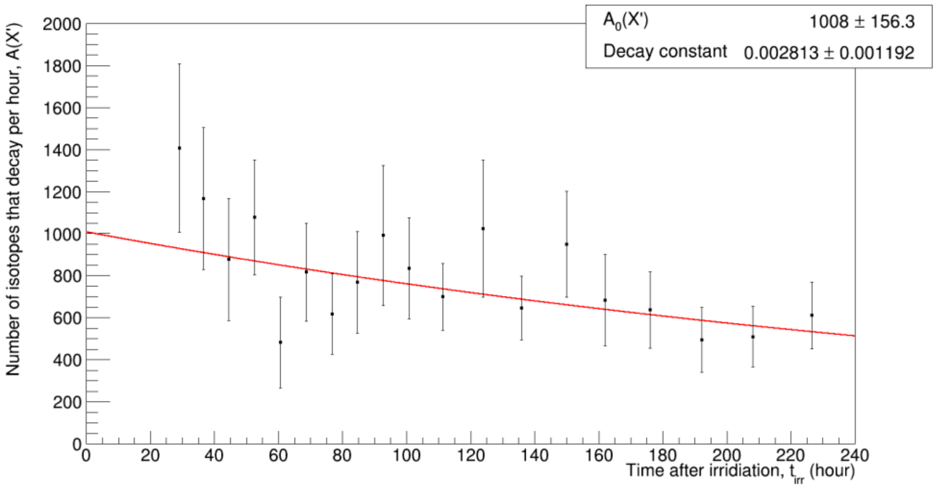
818.5 keV (^{136}Cs)





364.5 keV (^{131}I)

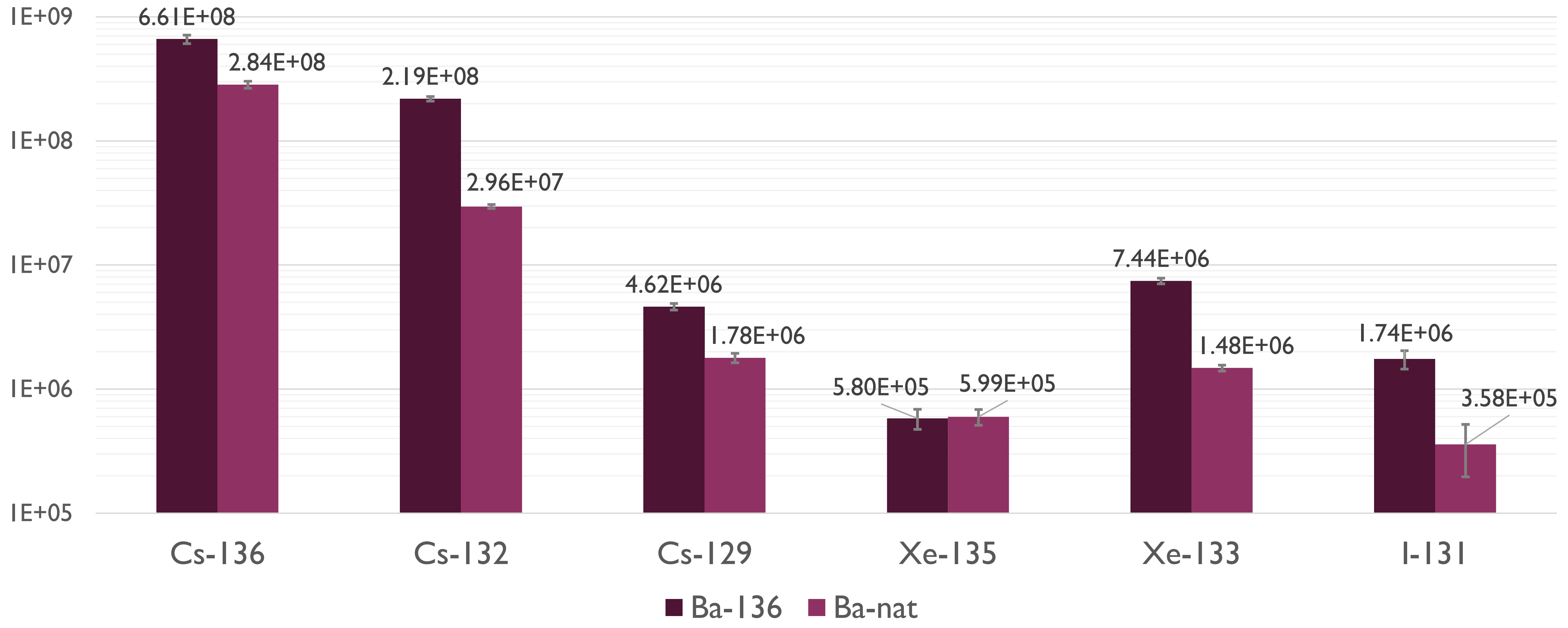




OBSERVED DECAY GAMMA PEAKS OF RESIDUAL ISOTOPES (RI) FROM ^{Nat}Ba

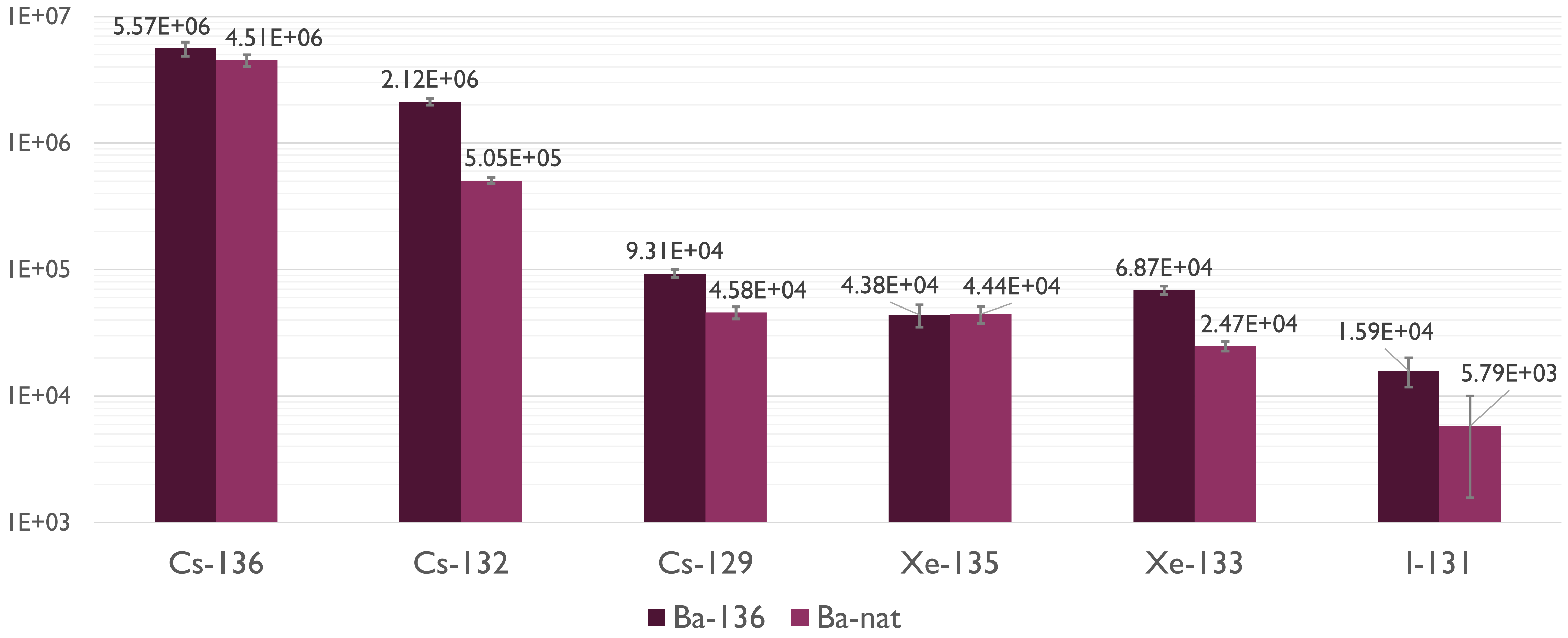
- For ^{Nat}Ba, there is only one additional peak compared to ^{136}Ba which is 661.7 keV from ^{137}Cs, but the intensity is too low and the half-life is 30 years. Hence, the errors for fitting the peak and decay curve will be extremely large.
- Since the irradiation time is relatively short, some peaks became too low to be measured: 505.8 keV, 630.2 keV and 1317.9 keV from ^{132}Cs.
- ^{138}Cs, ^{137}Xe, ^{136}Xe and ^{134}I was not observed due to their too short or too long half-lives (or stable).
- 529.9 keV peak from ^{133}I (half-life = 20.83 hours) was too low to be measured.

INITIAL NUMBER OF RI, $N_0(X')$



*The calculation was done using the most prominent peak from each RI.

ESTIMATION OF RI PRODUCTION RATE, *R*(X')



*The calculation was done using estimated irradiation time, assuming the sample was irradiated constantly.

COMPARISON WITH ^{127}I [1]

TABLE XV. Estimates for the overall pattern of yields, all in percentages, for muon capture in ^{127}I.

Reaction	Observed γ-ray yield	Estimated ground-state transition	Missing yields	Total yield
$^{127}\mathrm{I}(\mu^-, \nu)^{127}\mathrm{Te}$	7(2)	–	1	8
$^{127}\mathrm{I}(\mu^-, \nu n)^{126}\mathrm{Te}$	44(3)	10(10)	−2	52
$^{127}\mathrm{I}(\mu^-, \nu 2n)^{125}\mathrm{Te}$	15(3)	2	1	18
$^{127}\mathrm{I}(\mu^-, \nu 3n)^{124}\mathrm{Te}$	15(2)	1	−2	14
$^{127}\mathrm{I}(\mu^-, \nu 4n)^{123}\mathrm{Te}$	8(5)	–	−3	5
$^{127}\mathrm{I}(\mu^-, \nu 5n)^{122}\mathrm{Te}$	1.5(10)	1	–	2.5
$^{127}\mathrm{I}(\mu^-, \nu 6n)^{121}\mathrm{Te}$	1.0(5)	–	−0.6	0.4
$^{127}\mathrm{I}(\mu^-, \nu 7n)^{120}\mathrm{Te}$	–	–	0.1	0.1
$^{127}\mathrm{I}(\mu^-, \nu 8n)^{119}\mathrm{Te}$	–	–	–	0.02
Total	91.5(7)	14(10)	−5.5	100

- For ^{127}I, the ratio of 7*n* to 0*n* is 0.0125.
- For ^{136}Ba, the ratio of 7*n* to 0*n* is 0.0167.

[1] Measday, D. F., Stocki, T. J., & Tam, H. (2007). γ rays from muon capture in I, Au, and Bi. *Physical Review C*, *75*(4), 045501.

COMPARISON WITH ^{127}I [2]

- The estimate yield of *xn* emission was obtained from [1] whereas the estimate yield of *pxn* and *αxn* emissions were obtained from [3].
- For alpha emission in [3], (μ-,$\nu\alpha$) was observed only. Other emission like (μ-,$\nu\alpha n$) could not be observed as stated by author.
- In [3], the heaviest element with a measured yield of (μ-,$\nu\alpha$) is Ag (<0.01%). However, the yield of total alpha emissions for Ag is 0.5% in [4].

Reaction	^{127}I
(μ^-, ν)	8
$(\mu^-, \nu n)$	52
$(\mu^-, \nu 2n)$	18
$(\mu^-, \nu 3n)$	14
$(\mu^-, \nu 4n)$	5
$(\mu^-, \nu p)$	0.03
$(\mu^-, \nu pn)$	0.3
$(\mu^-, \nu p2n)$	0.2
$(\mu^-, \nu \alpha xn)$	0

[2] Measday, D. F., & Stocki, T. J. (2007, October). Comparison of muon capture in light and in heavy nuclei. In *AIP Conference Proceedings* (Vol. 947, No. 1, pp. 253-257). American Institute of Physics.

[3] Wyttenbach, A., Baertschi, P., Bajo, S., Hadermann, J., Junker, K., Katcoff, S., ... & Pruys, H. S. (1978). Probabilities of muon induced nuclear reactions involving charged particle emission. *Nuclear Physics A*, *294*(3), 278-292.

[4] Morinaga, H., & Fry, W. F. (1953). Nuclear capture of negative μ mesons in photographic emulsions. *Il Nuovo Cimento (1943-1954)*, *10*(3), 308-318.

CONCLUSION

- For offline measurement on both ^{136}Ba and ^{Nat}Ba, only 6 RIs were observed and measured:

  ^{136}Cs, ^{132}Cs, ^{129}Cs, ^{135}Xe, ^{133}Xe and ^{131}I.

- For ^{136}Ba, the absolute branching ratio should have an order of:

  ^{136}Cs (0*n*) > ^{132}Cs (4*n*) >> ^{129}Cs (7*n*) > ^{133}Xe (*p*2*n*) > ^{135}Xe (*p*) > ^{131}I (αn).

- For ^{Nat}Ba, the absolute branching ratio should have an order of:

  ^{136}Cs > ^{132}Cs > ^{129}Cs > ^{135}Xe > ^{133}Xe > ^{131}I.

NEXT TO DO

- Sensitivity measurement
- Gamma-gamma coincidence correction
- Calculation of absolute branching ratio *Br*(X')
- OMC strength calculation using proton neutron emission model (PNEM) and new model (developing)